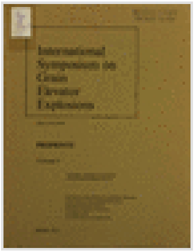

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This Preprint volume includes 23 papers presented at the symposium. Additional papers and proceedings of the discussions are given in Report NMAB-352-2, "International Symposium on Grain Elevator Explosions, July 11-12, 1978, Proceedings." The report on the symposium consists of this Preprint volume and the Proceedings volume.

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Volume 1 — PREPRINTS

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Senator Dick Clark
International Symposium on Grain Elevator Explosions
July 11, 1978 - 8:30 a.m.
National Academy of Sciences Auditorium, 21st and C St., N. W.
Sponsored by the National Materials Advisory Board of the
National Academy of Sciences on behalf of the U. S. Department
of Agriculture

I am very pleased to be invited to keynote this symposium today. I am pleased to see the cooperation among government agencies, the National Academy of Sciences, the Grain Industry, the Insurance Industry, Representatives of Unions and others who work in grain elevators, and scientists, both from the U. S. and abroad. I want to commend USDA for their efforts to initiate this symposium and all of you for your interest and participation.

Certainly, this is a very positive effort to deal with a very tough problem. It is tough because highly explosive grain dust is a natural and perhaps inevitable by-product of modern grain drying, processing and handling -- both on farms and in elevators with high speed equipment. Grain handling tends to be a high volume, low-margin operation. Per-bushel handling time and cost are very important. The combination of incentives and pressures for high speed handling, together with the inevitability of dust means that many elevators operate frequently very near conditions critical for an explosion. There is little margin for error, and mistakes end in tragic explosions.

The purpose of this symposium is to help reduce the odds of such an error -- to help managers find effective ways of making grain elevators safer. And, if possible, to do so without interfering with efficient operation.

My interest in grain explosions is real and immediate. I represent a major grain producing state. Iowa ranks second among states in corn production and second in soybean production. Iowa farmers depend on these crops for $3.5 billion in income. Both of these grains are major export commodities. They are handled and stored in commercial channels to a very important extent.

But Iowa ranks first in another, tragic statistic. It ranks first in grain explosions. Between 1958 and 1975 we had 23 explosions that killed 14 people and injured another 38 in grain elevators and feed mills. This implies a very serious risk for a state with more than 1100 firms with commercial grain storage capacity of more than 650 million bushels -- a very discouraging history of 7.1 explosions per 100 million bushels of storage capacity over 20 years. That measure of risk for Iowa is almost as high as Nebraska's ratio of 8.0 -- and more than twice as high as any other large grain producing state. Workers in Iowa elevators have a very important stake in lowering the odds of a grain explosion.

Important as the Iowa injuries and fatalities have been, they were far fewer than those that occurred in little more than one week last year in other states. Last December 22nd, 35 people were killed in an explosion at Westwego, Louisiana.

On December 27th, 15 were killed at Galveston, Texas. Two other explosions killed 3 more persons that same week in Mississippi and Illinois. Those explosions cost us about 10% of our export elevator capacity on the Gulf coast, in addition to the tragic loss of life. They raised again the question of control of these explosions in the most poignant way possible.

Following those explosions, I discussed this problem with people in USDA and the grain trade and with research scientists. I was impressed at the research detail available on grain dust explosions. I was impressed with the results of the efforts of the Grain Elevator and Processing Society in their symposium on grain dust explosions last October in Kansas City -- a symposium which some of you attended only a few weeks before the December explosions. But I have made a point to visit a number of elevators recently and I am also impressed with the difficulty and uncertainty faced by the elevator operator who must decide what equipment to install, and with the problem faced by USDA and other employers in their decision of whether or not conditions are safe for their employees.

From these observations, I developed a hypothesis. It seemed to me as a layman that we have reached the point where much of the basic research has been done. My hypothesis is that we now know quite a bit about conditions that will or will not sustain an explosion, and things that will or will not trigger an explosion. At the same time, I submit that we do not know nearly enough about what to say to the manager who is trying to decide what equipment and procedures are needed to ensure safety in his elevator, and what monitoring procedures he needs to support these systems. We do not know how to put our basic research into practice. Therefore, I conclude that using what we know about explosions to develop operational systems to protect elevators is a higher priority effort than is additional basic research.

So my first question to you concerns my hypothesis that we have done most of the basic research we need. And, I would broaden that challenge to include questions of whether we also have or can build the equipment we need to detect dangerous conditions and prevent explosions from happening. If there are gaps in our research we need advice on what should be done to fill them as quickly as possible. I hope such recommendations will be forthcoming from this symposium.

And, I want to leave you with two even tougher questions. Can we detect unsafe conditions and prevent fires and explosions without interfering with high speed, efficient grain handling operations? I am not suggesting that efficiency is more important than safety. The opposite is true. But I am suggesting that the cheaper and more practical safety equipment and procedures are, and the less they interfere with efficient high speed operations, the more likely they are to be installed and used widely -- and the more likely they will effectively prevent grain explosions.

Part of preventing explosions is knowing how best to give managers the incentive to actually install equipment and establish procedures that will prevent explosions. If the equipment is too expensive, it will be beyond the reach of some who need it. Others will find these high costs strong incentive to ignore the risk rather than buy the equipment or establish the procedures -- unless insurance companies or the state or federal government requires them. Perhaps tougher rules are needed. If so, we need to know that. However, if tougher rules are to be effective, their purpose and effect must be so clear that they cannot be contested.

In that connection, I would like to leave you with another challenge -- perhaps the most difficult of all. I hope that you will not pull any punches here. I have frequently heard the charge that the federal government's rules are at least partly to blame for some of the dangers of grain explosions. The kind of thing I hear goes like this: OSHA requires that dust levels on the inside of elevators be minimized for safety's sake. EPA, however, has rules that prevent dust from being vented directly outside in many cases, so it must be collected and concentrated. The suggestion is that concentration makes the dust more dangerous.

At the same time, I hear it said that USDA procedures add to the problem. USDA is responsible for preventing short weighting at the same time they are concerned about safety. USDA checks the dust that is collected to be sure that it contains dust only, and not grain particles as well. When grain is found in the dust, USDA has the dust collecting equipment re-adjusted to reduce the amount of dust and grain that is collected. The problem I hear about here is that this adjustment increases the dust inside the elevator.

And, USDA permits grain particles and grain dust both to be added back to grain. The elevator manager has a strong incentive to put the dust back because it is worth more as grain than as dust. The replaced dust then represents a hazard at the next handling point.

I do not know whether these practices are common or not. More important, I do not know whether they increase the risk of a fire or an explosion. I hope you will discuss these questions and if these charges have merit, and if they increase the risk of explosion, I hope you will make recommendations for new procedures and better rules.

In closing, I want to say again that I appreciate the opportunity to talk with you here today. What you are doing is important to the nation's export grain trade, and to our farmers.

I wish you every success with this difficult problem. Thank you very much.

TOWARD ACCIDENT PREVENTION IN THE WORKPLACE:

THE NIOSH PERSPECTIVE

James A. Oppold, Ph.D., PE CSP
Director
Division of Safety Research

INTRODUCTION

Modern man has learned that good public health practices can lead to control and prevention of many communicable diseases. The U.S. Department of Health, Education, and Welfare believes that good safety practices can lead to prevention of accidents in the workplace. But prevention requires commitment. Smallpox and malaria were eradicated in the United States only after a sincere commitment to prevention was made in all segments of society and the etiologies of the disease were understood. Similarly, prevention of workplace accidents requires a sincere commitment by management, labor, and government, and a clear understanding of the causes of occupational accidents. A comprehensive program of occupational accident epidemiology is therefore the keystone of any accident prevention strategy. The Department of Health, Education, and Welfare, through the National Institute for Occupational Safety and Health (NIOSH), is committed to using its experience in public health to help prevent grain elevator dust explosions.

I. MISSION OF NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

The Federal Government's recognition of the need for the study of health problems of workers began in 1914 with the establishment of the Office of Industrial Hygiene and Sanitation in the U.S. Public Health Service. Since then, realization of the scope and magnitude of the occupational safety and health problem in this country has grown, and strong legislation has been enacted to provide increasing occupational safety and health responsibilities for the Public Health

Service and the Departments of Labor and the Interior. One of the results of this growing concern has been the creation of the National Institute for Occupational Safety and Health (NIOSH).

NIOSH's mandate comes from four Congressional acts: the Federal Coal Mine Health and Safety Act of 1969, the Occupational Safety and Health Act of 1970, the Toxic Substances Control Act of 1976, and the recently enacted Federal Mine Safety and Health Act of 1977, which gives NIOSH new responsibilities for research and service programs in metal and non-metal mining.

While NIOSH is primarily a research agency, its mandated responsibilities also include testifying at public hearings in support of safety and health standards and providing technical assistance to labor and management. NIOSH also recommends safety and health standards to the Department of Labor for promulgation and enforcement.

Each recommended standard includes recommendations for an exposure limit, the use of labels and other forms of warning, the types and frequency of medical examinations to be provided by the employer, sampling and analytical methods, procedures for technological control of hazards, and suitable personal protective equipment.

To carry out this program, NIOSH was given the authority for "right of entry" into the workplace, as well as the right of access to worker records in order to investigate the relationships between the hazard and safety and health. NIOSH was also given the mandate to respond to requests from employers and/or authorized employee representatives to investigate and report the presence of hazardous or potentially hazardous situations in the workplace as well as produce annually a registry of effects of toxic substances.

The Institute also conducts education programs to help alleviate the shortage of qualified safety and health personnel, a responsibility which was given additional emphasis with the enactment of the Health Professions Educational Assistance Act of 1976.

While safety research and technical assistance have been important to the NIOSH mission since the Institute's inception, they had been carried out, until very recently, by a number of organizational groups within the Institute. However, in order to better coordinate safety efforts under way and to give workplace safety increased emphasis, the Division of Safety Research was established in Morgantown, West Virginia, in June 1977. As outlined in the June 14, 1977, Federal Register, Vol. 42, No. 114, the Division:

1. Serves as the focal point for the Institute's occupational safety research program; designs and conducts safety research aimed at preventing or mitigating injury to workers in all industries.
2. Conducts accident investigations and provides technical consultation relating to safety problems in all industries.

3. Develops criteria for recommended safety standards.
4. Develops and evaluates test protocols and develops regulations for certification of personal protective devices, industrial hazard measuring devices, and quality control programs.
5. Tests and certifies personal protective devices and occupational hazard measuring devices.

NIOSH's effort is guided by several principles that may be familiar but are worth reiterating:

1. NIOSH will emphasize, generally through interagency agreements, cooperative activities with other Federal safety research programs. The NIOSH program should be complementary not duplicative.
2. NIOSH efforts will be responsive to the needs of our sister agency, the Occupational Safety and Health Administration, and will aid in the effort to find practical options for dealing with real world problems.
3. NIOSH will work closely with professional groups, management, and worker representatives.
4. NIOSH will strengthen its university research and training grant Programs.
5. NIOSH will give special emphasis to national priorities such as the Energy Program established by the Administration.

When Congress passed the Occupational Safety and Health Act of 1970, it was widely recognized that the shortage of trained occupational safety and health professionals in the United States was acute. In the Act, NIOSH was given the responsibility for developing programs to help alleviate the shortage. Training has always been an important initiative in NIOSH, and recently nine university Educational Resource Centers have been funded to coordinate undergraduate and graduate education in schools of engineering, public health, nursing, and medicine. Additional centers are expected to be funded in the future. It is hoped that through these new programs, safety professionals, industrial hygienists, occupational nurses, and physicians will learn to work closely and to interact with epidemiologists, psychologists, industrial toxicologists, and biostatisticians. It is also hoped that the influence of these programs will be felt in schools of business and law which educate large numbers of the future decision makers in American industry.

II. SAFETY RESEARCH

Increased emphasis on educational programs, such as those being established in NIOSH Educational Resource Centers, is essential in solving workplace safety problems in the long-term. Research, however, is the key to problem solving in the intermediate term.

NIOSH safety and health research is conducted in-house and through grants and contracts. Fifty-five safety and health research grants are being funded by the Institute and 12 contract safety research projects are under way. The primary objective of all NIOSH safety research is to reduce occupational injuries and fatalities.

Recognizing that accidents typically involve many interrelated behavioral and physical factors, NIOSH has initiated an ongoing effort to use surveillance techniques to isolate specific problem areas. Subsequent technological investigations can then lead to educational aids and control measure recommendations directed principally toward prevention. Of course, accidents may still occur, particularly in extra hazardous occupations, despite all preventive efforts.

The groundwork for this extensive safety program has been firmly laid. The projects already initiated within NIOSH can be categorized generally as surveillance, prevention, or protection efforts.

Surveillance

Surveillance projects involve gathering, evaluating, and utilizing accident and/or injury data to identify information and technology gaps, establish research priorities, and measure program impact. The following are examples of current projects in this area.

1. Evaluation of injury data reported on OSHA 101 forms. This project involves an in-depth review of the OSHA injury reporting

system with a view toward determining its adequacy for fulfilling NIOSH safety surveillance system requirements.

2. Collection and evaluation of data on agricultural injuries recorded in the National Data Collection System (agricultural).
3. Development of methodology for collection, organization, and storage of data from diverse and often apparently incompatible sources so it can be accessed through use of standard statistical software packages.
4. Development of methodology for identification of high-risk industries by standards as well as nationwide occupational injury experience.

Prevention

Prevention projects provide safety guidance and information to specific occupational groups through detailed studies of preventive control measures. The following are currently under way:

1. Studies to identify and control causal factors of high rates of injury incidence in selected occupations.
2. Development of work practices criteria and standards on safety for inclusion in the Department of Labor standard setting system.
3. Detailed study of behavioral, motivational, and psychological factors involving job safety in the refining industry, a traditionally high-risk occupation.

4. Study of human factors affecting job safety in materials handling, including an analysis of injury record data associated with the use of the various classes of materials handling equipment.

Protection

Current research in personal protective equipment has centered on developing safety criteria suitable for use as the scientific basis of recommended standards for the personal protection of workers. A matter of particular concern is the respirator. Respirator research currently includes studies to quantify respirator fit parameters, and to consider the effect of workers' physical characteristics, such as face measurements and amount of facial hair, on respirator protection.

In addition to these continuing projects, NIOSH has initiated a variety of new safety projects. Examples of these projects include the following:

1. Causal factors in building and highway construction,
2. Causal factors in the oil and gas industry,
3. Machine guarding,
4. Ergonomic characteristics of high-risk jobs,
5. Assessment of safety in energy industries,
6. Warning devices, and
7. Safety in manufacture and storage of explosives and pyrotechnics.

III. HAZARDOUS SUBSTANCES STUDY

Over the years, considerable resources in both the public and private sectors have been devoted to research toward an understanding of the concentrations of oxidizable dust and oxygen and the ignition levels required to produce explosions. Because of its concern over these specific issues, NIOSH has proposed to the National Academy of Sciences (NAS) that an Advisory Committee on Hazardous Materials and Situations be established to recommend safety standards and develop safety educational materials. Working in conjunction with the National Research Council, the National Research Advisory Board, other Federal agencies, and public consensus standard-making organizations, the Committee would perform a number of tasks including the following:

1. Complete an already in progress classification system of hazardous chemical gases and vapors found in the industrial workplace of interest to NIOSH according to the National Electrical Code (NFPA No. 70, 1978), Chapter 5, Special Occupancies, Articles 500 through 503, which classify hazardous locations.
2. Define the physical and chemical nature of atmospheres of oxidizable dusts found in the workplace and to characterize their hazards in air in the presence of various sources of ignition.
3. Classify these dusts for Class II locations (NFPA No. 70, 1978), Article 502, National Electrical Code, in which explosions of dust groups E, F, and G might occur.

4. Evaluate the hazards in light of the preceding requirements and develop a data matrix or matrices of physical and chemical properties and ignition energies and the corresponding fire hazards of vapors and dusts. The matrix or matrices together with existing classifications will assist in assigning tentative classifications to new materials as they become of interest.
5. Make recommendations for standards for operation of electrical equipment and other sources of ignition in hazardous areas defined in the matrix or matrices. When information is found to be missing or inadequate, research recommendations will be made.

Among results of the committee's efforts should be a series of reports containing guidelines for classifying industrial hazards, particularly those involving flammable and combustible materials (solids, liquids, vapors, gases, etc.). The National Electrical Code (NFPA No. 70, 1978) will be used as a guide for these classifications.

While grain dust explosions are of particular interest in these efforts, NIOSH is responsible for making accident prevention recommendations for all workplaces in which oxidizable dust is a problem. The Institute's focus, therefore, will remain wide even though current areas of concern such as grain handling and storage will receive top priority for research.

IV. SUMMARY

The NIOSH Division of Safety Research is committed to helping meet the need for data on incidence, prevalence, and severity of accidents in the workplace and to understanding the causes of occupational accidents. Where unanswered questions stop progress in problem solving, special research must be initiated to find the facts. Part of NIOSH's responsibility is to carry out this research and to help coordinate the national effort to prevent not only grain dust explosions but all dust explosions. The problem is complex, its solution elusive, but NIOSH believes a safe and healthy workplace in grain handling facilities is possible. The sooner there is a clear understanding of the causes of these fires and explosions and feasible controls are installed, the quicker worker lives will be saved, injuries reduced, compensation costs lowered, and property damage minimized.

JOHN E. ALBERTSON
SAFETY DIRECTOR
AMERICAN FEDERATION OF GOVERNMENT EMPLOYEES

GRAIN ELEVATOR FIRES AND EXPLOSIONS
(AFGE POSITION)

INTERNATIONAL SYMPOSIUM ON
GRAIN ELEVATOR EXPLOSIONS
NATIONAL MATERIALS ADVISORY BOARD
WASHINGTON, D.C.
JULY 11, 1978

BACKGROUND

The grain handling industry through its annual shipment of an estimated 15 billion dollars worth of grain to Asia, Africa, the Middle East and Europe, has become to the United States what oil is to the Arab countries.

Until 1976 the determination of the quality, grade and weight of American grain to be shipped to other countries was made by inspectors of private inspection agencies licensed by the Department of Agriculture. The passage of the Federal Grain Inspecton Act in 1976 came about as the result of certain practices of the large grain corporations purportedly involving bribery of these privately licensed inspectors. The purpose of this law was to reassure international grain customers that they would receive the weight and quality of the grain that they were paying for.

The American Federation of Government Employees as the nation's largest labor union of Federal employees, representing over 700,000 Federal employees, has long been in the forefront of the struggle for better safety and health working conditions, policies, practices, and programs throughout the Federal government. Our concern has always been deep and constant.

On December 19, 1977, just three days before the Continental Grain elevator in New Orleans blew up, AFGE won exclusive recognition rights for the Federal Grain Inspectors who are employed by the Department of Agriculture Federal Grain Inspection Service.

Even before the winning of representation rights by AFGE for these inspectors, our organizers were told of the extremely hazardous working conditions existing in these elevators and the apparent lack of interest by management in getting them corrected.

Just like any other business, when profits are big, safety can become a nuisance and the international grain industry is extremely profitable, to the tune of hundreds of millions of dollars. For most of the export elevators safety isn't a nuisance; it doesn't even exist. The tragic statistics -- 50 injured, 50 dead, 13 of the dead Federal Grain Inspectors, 23 explosions in a period of 20 months -- bear out the fact that safety has received scant attention by the industry. Part of the blame must be assumed by the Department of Agriculture, which for the past year, has had a close look at the industry and its practices and had remained silent until two major elevator explosions jolted the publics interest. It is the general overall feeling of the Federal Grain Inspections that the Department of Agriculture has tried to keep a "low profile" in the grain storage facilities, so as not to interfere too greatly in the speedy loading of grain into the holds of ships. It is the same old story in the grain industry as it is in any other big industry, "Production at any cost."

THE GRAIN INDUSTRY AND FEDERAL INSPECTORS

Workers in the grain industry are exposed to a variety of occupational hazards, such as grain fires and explosions, toxic grain fumigants, respiratory diseases from grain dust, falls from heights, and unguarded machinery. Unlike the employees of the grain companies, who have specified tasks to perform and specific areas to be in, the Federal Grain Inspectors must be in all areas of the elevator thereby exposing them to the whole range of hazards that are present in any elevator at any given time. Also, unlike the employees of the grain elevator company who have the full protection of the Occupational Safety and Health Act and have the right to ask for an OSHA inspection, the Federal Grain Inspectors are only covered by one small section of the Act and do not have the right to ask for an OSHA inspection.

Specifically Section 19 of the Act, which is the only part of the Act which pertains to coverage for employees of the Federal government, states:

> "It shall be the responsibility of the head of each Federal agency to establish and maintain an effective and comprehensive occupational safety and health program which is consistent with the standards promulgated under Section 6."

This automatically takes the Federal Grain Inspector out from under the umbrella protection, which is given to the employee of the elevator company by the Occupational Safety and Health Act. Instead, it places them under the suspect protection provided by the Department of Agriculture. This suspect protection can be documented by the fact that since the Federal Grain Inspectors have been represented by AFGE we have received numerous complaints from inspectors that the Department of Agriculture has shown a lack of concern for the safety of its employees. Numerous reports from the Federal inspectors indicate that they are ill-equipped with personal protective equipment and have been at various times instructed by their supervisors to ignore unsafe conditions and accidents that occur.

The giants of the grain industry have accepted Federal inspection reluctantly. At best, the companies treat the Federal inspectors with icy contempt, and according to the inspectors that have been interviewed by AFGE, the companies refuse to acknowledge much safety for their own employees and even less for the Federal inspectors who work on their premises.

As examples of the open hostility shown by the companies, the inspectors cite company failures to notify Federal personnel when fires occur; they also say that company officials won't even advise them of the location of emergency power cutoff switches along the conveyor system.

FIRE AND EXPLOSION HAZARDS

Explosion of grain and other combustible dusts have been occurring for well over 100 years. Everyone agrees that grain dusts are highly combustible -- even more explosive than coal dust which is used as the standard. Almost any ignition source and the proper grain dust concentration in the air can cause a violent explosion. Standing dust on floors and ledges causes an additional risk, since the shock waves from a primary explosion stir it up, giving the fuel for more severe secondary explosions.

This situation is aggravated by the fact that most elevators have either inadequate dust control programs or none at all and most of them have no housekeeping program. In addition to that, the existing regional and terminal elevators are operating 24 hours a day, 7 days a week with no shut down for maintenance, housekeeping, or anything else. In fact, the Federal Grain Inspectors reported to us that most of them had been working 84 hour weeks during the period of Thanksgiving through January 1978. The only day any of them had off during that period of time was Christmas. They said the long hours were due to understaffing and the continuous operations of the elevators. They live in constant fear of explosions because the possibility of fire is a daily threat.

Definitions of what makes up an "imminently hazardous" situation will always vary. In the eyes of Federal inspectors -- most of them in their mid-or late twenties and recent graduates of agriculture colleges -- life and limb are much more precious than the rapid movement of grain. Of course, grain elevator operators, who say that delays in the movement of grain cost them 8,000 dollars or more an hour, are willing to take considerably higher risks, at least from their cozy office facilities.

ACTIONS TAKEN

Recently nine different unions, including the American Federation of Government Employees, representing workers in the grain industry met during a week long safety training institute concerning grain elevator fires and explosions. This institute was conducted by the University of Wisconsin School for Workers.

It was the unanimous opinion of those attending the institute that the violations found by the Occupational Safety and Health Administration, as a result of an inspection at the Galveston, Texas elevator, were also present in most of the grain elevators throughout the country. Among those conditions cited in the statement were:

1. Lack of notice before welding operations were started, or allowing welding in explosive dust conditions.

2. Use of compressed air for cleaning.

3. Failure to clean up grain spills immediately.

4. Lack of employee training on dust and fire explosion hazards.

5. No fire alarms and if a fire alarm is in existence, it is most generally not tied in with local fire departments.

6. Motors and lighting systems which are non-explosion proof.

7. Use of locomotives without spark arrestors in the elevators.

It was also agreed by those at the meeting, who were also speaking for the rest of the grain elevator workers, that inadequate maintenance is universal throughout the industry and is a major cause in the increase of fires and explosions. In fact, it was stated that many elevators have no maintenance personnel whatsoever and that most elevators would rather lay off personnel during slack periods than putting them to work cleaning up the elevators.

According to Professor Richard Ginnold, who was conducting the training Institute, another problem involves the practice of the industry to return the collected dust back into the grain prior to shipping in order to add more weight. Under present standards, elevators are permitted to introduce dust and waste matter to shipments of grain.

According to the statement, OSHA officials and private experts said, returning dust to the grain is "a very unsafe practice but no action has been taken to regulate it because of the economic questions involved."

In Kansas alone, the statement noted, the value of grain salted with dust is 10 million dollars, a fact which the unionists attending the conference characterized as a blatant favoring of profits over workers safety.

The idea for the establishment of a safety clearinghouse to guard against job hazards unique to grain elevator workers was one of the products arrived at during this week long training session.

CONCLUSION AND RECOMMENDATIONS

It is quite obvious that a major cause of grain fires and explosions are as a result of the grain industry's neglect of recognized safety requirements and the practice of marketing dust as grain. These tragedies were not only responsible for bringing attention to the unacceptable working conditions to which the Federal Grain Inspectors are exposed, but they also pointed out the utter disregard by the grain elevator operators and the Department of Agriculture for the safety and health of their employees.

I must at this time point out that selfishly I am thinking of the protection from harm of the Federal Grain Inspectors, whom we represent, but humanely I am thinking of the protection from harm of all of the workers in the grain industry.

It is therefore recommended that:

1. The practice of returning collected dust to the grain before weighing out greatly aggravates the already existing dust collection problem and should be prohibited. By returning the dust to the grain 4 or 5 times creates an additional load on the dust control systems and increases dust concentrations in the elevators.

2. Vacuum cleaning systems for grain spills, walls, and ledges should be used rather than allow the present method of blowing down compressed air and sweeping. Admittedly, these are expensive and must have good maintenance.

3. Elevators should be shut down periodically, at least once a day, to allow for a preventative maintenance program to be carried out. Some of the major ignition sources responsible for explosions are: Friction in the bucket elevator, electrical sparks, overheated bearings, and spontaneous combustion. A well organized and standardized preventative maintenance program will prevent these items from building up.

4. Develop and institute an employer training program, highlighting the dust control program, as well as, safe work practices to be adhered to. A safe operation largely depends upon employees

who are properly informed and aware of potential hazards.

5. Strict enforcement of a written welding permit system administered by the grain elevator operator as a control against unauthorized welding and cutting. Welding in the elevator should be done only in emergencies and then only after eliminating dust accumulations, wetting down the area, isolating it and shutting down any conveyors or machinery in the area.

6. Install overload controls to stop the head pulley when the belt slips or the bucket elevator becomes clogged, heat sensor alarms to warn against overheated bearings or other hot spots, and explosion proof electrical systems and equipment.

7. Install adequate exits, sprinkler systems, develop emergency evacuation plans, and give fire safety training to all employees.

8. Provide for all employees periodic physical examinations and for all new employees preplacement physicals. Provide for an active and ongoing program of monitoring potential health hazards, so as to maintain good control of the environment.

9. Provide eating and sanitary facilities. These should include locker rooms adequate for both men and women, including shower facilities for clean up, as well as in case of pesticide contamination.

10. Remove the grain inspection laboratory facilities a safe distance from the elevator.

11. Provide for better coordination and communication between elevator personnel and Federal Grain Inspection personnel such as notification in the event of a fire or other hazardous conditions in the elevator.

12. Provide for more active participation by the Department of Agriculture with the grain elevator operators in the devising of systems for the elimination of static electricity build up and also for better methods for the collection and disposal of grain dust.

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TECHNICAL SURVEY OF GRAIN DUST EXPLOSIONS

by

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SUMMARY

The principal aspects of dust explosions involving grain are surveyed, ranging from the basic properties of the explosions to test methods and the assessment of explosion hazards.

Common sources of ignition of explosions are listed, together with means of avoidance, but it is stressed that the prevention of ignition cannot be the sole protection against the hazard of explosion.

Some discussion is given of fires in grain dust, as these may precede or follow explosions.

The principal relevant methods of explosion protection are surveyed with particular reference to explosion relief venting. Application of explosion protection methods to grain elevators is discussed and indication is given as to where future research is necessary.

INTRODUCTION

Although dust explosions have been recorded for over a century appreciation of their true character was relatively slow in developing. In particular great difficulty was experienced in accepting that an explosion could be caused by the dust alone and that the presence of a flammable gas to support the explosion was not necessary. It was not until late in the nineteenth century before it was generally accepted that dust explosions in coal mines could be initiated and sustained by coal dust alone without needing support from flammable mine gas. When the position was finally clarified early in the present century explosions in numerous other industrial dusts had occurred and the way was open for a more rational assessment of the explosion hazard and the need for adequate precautions.

Because the production and handling of grain on an industrial scale also has a long history the hazard of dust explosions has been common knowledge in the industry for many decades. In the grain industry, as in many other occupations, the potential hazard of dust explosions has increased with time because of the greater size of individual installations, their increase in number, and the predominance of continuous over batch production. Because a dust explosion is a combustion process, releasing energy, the larger the size of the dust suspension the more energy there is to release. Thus increasing scale in industrial activity inherently increases the explosion hazard in terms of potential release of energy. On the other hand there have been significant improvements in methods of elimination and protection against explosions, which counteract the tendency towards increased hazard. However as present knowledge indicates, there is still a considerable hazard to life and property in the handling of grain, and further methods are clearly needed to reducing the number and destructive potential of grain dust explosions.

In order to set the problem of dust explosions in perspective, a survey is given of the principal important aspects. This will assist in establishing the nature of the problem and will show the need for the various tests and protection methods described subsequently. In such a survey it is clearly not possible to cover all aspects in considerable detail, and therefore reference is made to a book on dust explosions and fires (Palmer, 1973) from which further information may be gained. The topic of fires in dusts is also covered in the book, and protection against fire is as necessary as against explosion because fires may either precede or result from explosions, and their potential for damage to operatives and installations is considerable.

CHARACTERISTICS OF EXPLOSIONS

Expansion effects

A dust explosion is the combustion of a dust cloud and results either in a rapid build up of pressure or in uncontrolled expansion effects. The gas (usually air) in which the dust is suspended takes part in the explosion and so both the nature of the dust (i.e. the fuel) and the gas (i.e., the oxidant) are important. As different types of grain have different compositions, some differences in expansion effects in explosions are therefore to be expected.

The expansion arises principally because of the heat developed in the combustion, and in some cases, to gases being evolved from the dust because of the high temperature to which it has been exposed. The heat generated is eventually lost to the surroundings so that the explosion pressure effects are transient. However, the flame speeds are high compared with the rate of cooling so that the explosion effects become manifest.

Deflagration

In grain dust explosions the rate of flame propagation is fast compared with the rates of flame spread in fires. In enclosures such as plant or buildings flame speeds can range from hundreds of metres per second to the slowest which are of the order of one metre per second. The type of explosion which occurs in grain elevators is termed a deflagration and an important property is that the flame speed is less than the velocity of sound. In broad terms, the explosion pressure in a volume increases to the same extent throughout the volume, at a given time. There may be slight pressure differentials due to friction at the walls but these are relatively unimportant. In terms of the pressure produced on the walls, the effect is that of a hydrostatic pressure rather than a shock loading.

Detonation

In a detonation the flame speed is supersonic and it is accompanied by a shock wave. The velocity of propagation is of the order of 1000 m/s. Whether or not a true stable detonation can occur in a dust explosion in industrial plant has not yet been established. In any case a detonation would be initiated as a deflagration, and in the present context only deflagrations need be considered. This is a fortunate happening because deflagrations are simpler to deal with than are detonations.

In a deflagration as the flame moves away from the ignition source its speed is slow, whereas compression waves arising from the expansion effects will travel through the unburnt dust cloud at sonic velocity. A signal is thereby sent ahead of the flame giving warning that expansion or pressure rise is occurring. Explosion relief vents or pressure detectors can then operate during the early stages of the explosion and steps can be taken to prevent the maximum explosion pressure from developing. In a detonation the flame accompanies the pressure wave and no advance signal is received by a relief vent or a pressure detector, and no time for the operation of safety measures before the arrival of the flame is available.

Flame speed

In a dust explosion the flame speed is not constant but depends on a number of factors. In the present state of knowledge the flame speed cannot be related simply to the composition of the dust, including its moisture content, or to its heat of combustion. The flame speed depends also on particle size, smaller particles burning rapidly and on the stirring effects due to turbulence generated both by the running of the plant and by the explosion itself.

Primary and secondary explosions

The propagation of flame through a preformed dust cloud is termed a primary explosion. Traditionally, primary explosions occurred inside plants, but if the protection methods were inadequate so that the explosion burst out of the plant into the building, then it could raise up dust in the building and ignite it. The resultant explosion is termed a secondary explosion, in that it is initiated by the presence of the primary. In large scale modern plant, the initial dust cloud may occupy only one unit, or a fraction of the volume of a large unit, and if ignited it can raise further dust within the plant itself. The results may also be regarded as a secondary explosion but the original distinction between explosions in plant and in buildings has been lost.

EXPLOSION PROPERTIES OF DUSTS

In order that the explosion can develop, the dust cloud must be ignited and a source of ignition is necessary. The source may be thermal, electrical or mechanical in origin and further consideration is given below. The source must be present for the explosion to be initiated.

Even if the source is present, the explosion can only propagate if the concentration of dust in the cloud is within specified limits. These are the lower and upper explosibility limits, the former is sometimes called the minimum explosible concentration. If the cloud is below the lower explosible limit, then there is insufficient grain in the cloud for the explosion to be sustained and the flame does not propagate. If the concentration is above the upper explosible limit then the suspension is too rich and the flame is again quenched. Between the lower and the upper limits the concentration of dust is favourable for flame propagation, and the actual concentration will affect the severity of the explosion. In practice the lower explosible limit is a fairly well defined quantity, and tests are available for this measurement. The upper limit is less well defined, and corresponding tests are not yet available.

When an explosion occurs in a plant or building spectacular destruction may result if the explosion is iniitally completely confined and the plant is ultimately too weak to withstand the full force of the explosion. Two of the factors influencing the violence of the explosion are the maximum explosion pressure and the maximum rate of pressure rise. Where it is intended to contain the explosion within the plant, the strength of the plant must exceed the maximum explosion pressure that can be developed. The maximum rate of pressure rise (or the average rate) is often used in connection with the design of explosion relief venting. Where the rates of pressure rise are high, the products of combustion are being generated rapidly, so that the amount of relief venting will need to be greater than in explosions with lower rates of rise.

TESTS FOR THE EXPLOSIBILITY OF DUSTS

Test methods for evaluating the explosibility of dusts were devised by the US Bureau of Mines, Pittsburgh; the methods are extensive and include investigation of both dust suspensions and dust layers with a wide range of ignition sources under a variety of conditions of dispersion. A full account of the equipment and test procedures has been published (Dorsett et al 1960) and detailed results for a wide range of grain dusts are available (Jacobson et al 1961).

The tests of particular relevance to grain elevator explosions are for the measurement of the following parameters.

Minimum ignition temperature
Minimum ignition energy
Minimum explosible concentration
Maximum explosion pressure
Maximum rate of pressure rise

If it is desired to obtain explosion protection by reduction of oxygen level in the plant, then a test for the maximum permissible oxygen concentration is available.

Published test results may be used readily where broad generalisations as to explosion hazards are all that are required. For more detailed considerations, however, it may be necessary to commission tests from the materials being handled in the plant under consideration. This is particularly important where, for instance, fines produced by abrasion may have significantly different compositions from the grain itself. Particle size and moisture content are also important, the explosion properties of material from a fabric filter unit may differ significantly from those in a conveyor in the same plant.

The validity of the results obtained by tests depends directly upon the representative nature of the samples taken in the first place.

The US Bureau of Mines have put forward a method of indexing dusts according to their explosibility (Jacobson et al 1962). Ratios called the Ignition Sensitivity and the Explosion Severity are calculated for the dust and the Index of Explosibility is obtained as the product of the two ratios. The Ignition Sensitivity is calculated by multiplying together minimum ignition temperature, minimum ignition energy, and minimum explosible concentration of a standard dust (Pittsburgh coal dust) and dividing the product by the corresponding values for the dust being tested. The explosion severities obtained by multiplying together the maximum explosion pressure and maximum rate of pressure rise of the dust being tested and dividing by the corresponding values for Pittsburgh coal dust. The Index of Explosibility, for many grain dusts, then is shown to be of order unity. The method gives a useful guide particularly if the dust being tested is shown to have an extreme value for the Index of Explosibility.

SOURCES OF IGNITION

Although there are a vast number of different sources of ignition having various temperatures, energies, durations, etc., they can be conveniently grouped as follows:

Flames
Smouldering
Hot surfaces
Welding and cutting
Friction and impact
Electric sparks
Spontaneous heating

As far as possible sources of ignition must be excluded from the plant. In practice their presence cannot be completely eliminated because they may arise from a breakdown or even be introduced maliciously. So the exclusion of sources of ignition cannot be relied upon as a sole method of protection of the plant. The likelihood of a source being present can be much reduced by good design and management and should be regarded as an essential requirement for safety. Exclusion of ignition sources is a necessary first step, but other methods of explosion protection are required in order to gain acceptable safety.

Flames are potent sources of ignition, and there is no minimum safe size, and hence the basic step against ignition must be to prevent their coming into contact with flammable dust.

Smouldering is an alternative form of combustion, characterised by the absence of flame and the burning not always being visible. Smouldering may initiate a dust explosion by:

1. The dust cloud coming into contact with deposited smouldering material.
2. The smouldering being converted into flaming by an air draught.
3. The smouldering material being itself being dispersed into a cloud, producing flame.

Hot surfaces can arise from mechanical fault, eg overheated bearings, belt slippage, or by bad working practice, eg exposure of dust clouds to electric lamps. Hot surfaces are of course present in dryers and particular care is needed when they are handling dusty materials. With hot surfaces the dust can stay in the vicinity of the surface, so that slow build up of heat can lead to ignition. The ignition temperature of dust deposits are often much lower than those of dust clouds.

Welding and cutting operations are the source of many incidents. Protection must be based mainly on the rigorous adoption of correct working procedures. Necessary steps include the removal of all flammable materials from the inside and the outside of the plant unit being welded, the introduction of a permit to work system, the removal of all combustibles in the vicinity of the welding operation, the provision of adequate ventilation, and the ensuring that suitable fire fighting equipment is available. In spite of the well known hazard associated with welding operations, the number of fires and explosions attributed to this cause continues to be unacceptably high and redoubled efforts will be needed to improve the position. Ignition of dusts by friction or impact is a subject which is not yet on a rigorous quantitative basis. Ignition by friction or impact is more likely to arise in connection with powered operations, rather than manual ones, and although the occurrence can sometimes be foreseen and designed out there will be cases where, due to failure of plant or personnel, ignition can occur. Explosion and fire protection are then necessary to give required safety.

Explosions due to electric sparks have two principal origins, electric utility mains power and static electricity. The electric mains, or batteries, are powerful sources of ignition because the energies available are usually much greater than the minimum ignition energy of the dust cloud. Special precautions are needed in the design of equipment such as switches, motors and lights, exclusion from the dusty atmosphere being the principal aim. Although considerable attention is rightly paid to the specification of the electrical equipment, it is important that connections, wiring, cables, are specified with equal care.

Static electricity is generated during the transportation and conveying of grain. The charge generation cannot usually be avoided and protection against ignition relies on the grounding of plant to earth. It is essential that all metalwork in grain handling plant is grounded because isolated metal components, even if small, can rapidly accumulate sufficient charge to give hazardous sparks. Particular care is needed where insulating materials such as plastics are present, to ensure that either they are sufficiently conductive to allow the charges to drain to earth or that they cannot otherwise give hazardous sparks. By virtue of its movement the grain itself is liable to acquire a charge and means must be provided in bins, silos etc for this charge to flow to earth. All such containers need to be grounded. Operatives may also become charged, by direct contact or by induction. Antistatic footwear for operatives may be necessary to overcome the problem. The problem of static electricity is generally acknowledged as being much reduced if the relative humidity is not below 60 per cent. However, whilst this may be true at comfortable temperatures, there may be difficulties if the temperature becomes extreme. Technically, it is the moisture content of the material which is an important factor and, under equilibrium conditions, may be low at high relative humidities, if the temperature is low.

Spontaneous heating and ignition involve chemical reaction between the dust and the air. The reaction generates heat and if the reacting material is of size and shape such that heat losses do not compensate for heat generation, then the temperature of the mass can rise, so accelerating the reaction. However the process is slow and, with grain, would lead to spoilage of the products. The problem is accentuated by the presence of excess moisture, which encourages biological as well as chemical action. Protection is obtained by monitoring the material, usually under storage, and cooling, mixing, or sub-dividing the mass to reduce temperature and prevent spoilage.

FIRES IN DUSTS

Unlike dust explosions there are two types of burning in dust fires, flaming and smouldering. The type of burning depends on the characteristics of the dust, the dimensions of the deposit, and the ease of access of air. With flaming the rate of heat release is likely to be higher than with smouldering. If a suitable ignition source is present the burning of dust layers with flame can take place provided the quantity of dust is sufficient, it is distributed favourably, and the supply of air is adequate. Whether a particular dust can burn with flame so as to give a fire hazard may need to be determined by test because it cannot be predicted reliably. Relatively little information is available on the burning rates of dust layers and until the theory of flame propagation over layers is developed, recourse must be made to experiment for information on burning characteristics. However, the sources of ignition which give rise to dust fires are the same as those for dust explosions, and the precautions to be taken are similar.

Two types of smouldering can be distinguished. In the first the smouldering propagates over the surface of the dust deposit or, if the deposit is thin, the smouldering burns practically the full thickness. The second type is ignition within the deposit the smouldering propagating through the dust, mainly upwards until it reaches the surface. Propagation across the surface then proceeds as with the first type. Propagation through the deposit is usually the result of the buried ignition source, or ignition on a hot surface. Some information is available on the smouldering rates, and the effect of air flow, and on the transition to flaming (Palmer 1973).

There are no special types of fire detector designed solely for use against dust fires. When the dust is burning with flame it may well be emitting heat, light and smoke. Detectors are available which are sensitive to these emissions, but difficulty frequently arises because of interference by dust entering the detector. False alarms may then be a problem.

Automatic sprinkler systems fulfil the dual purpose of detecting fire and attacking it. They can give protection against fires in dust providing the heat output from the fire is sufficient to activate the sprinklers. This requirement would usually mean that the dust was burning with flame and that the sprinkler heads were directly accessible to the products of combustion of the fire.

If the dust is smouldering the rate of burning is usually slow, hence the heat release is also slow. The quantity of smoke produced varies with the nature of the dust and reliable detection can be very difficult.

Fire detection systems do not have sufficiently rapid response to enable them to give warning of explosion. In addition, they may be rendered unserviceable by the effects of explosion, so that the fire fighting function of sprinklers may be lost.

Fires in dusts may be extinguished either by allowing the fire to burn all the dust, or by applying extinguishing agents, or by treating the dust deposit so as to exclude oxygen from the fire. Whichever method is used great care should be taken to avoid disturbing the dust into a cloud because burning material is present and may cause an explosion.

Allowing the fire to burn itself out may be possible for small amounts of dust but is not likely to be generally acceptable. If the method is used continuous watch must be kept at all stages to ensure that changes in burning can be dealt with. Such changes are likely to arise from sudden air draughts, the burning away of the dust below its surface, and the failure of structures under the action of heat.

The usual approach is to extinguish the fire. Selection of the most suitable agent depends on factors such as the amount and situation of the dust, the presence of nearby equipment. The extinguishing agent most commonly used for grain is water, which should be applied from a low pressure spray, and not from a high pressure jet. The action of high pressure water could be to disperse the dust into the air thus giving rise to an explosion hazard. If the dust layer is 1 m or more in thickness water applied as a spray may not penetrate into the mass of the dust. Vigorous stirring of the dust must not then be made but either it should be gently removed by digging and the spray application continued, or the use of a wetting agent in the water may be tried. Because of the necessity of applying water gently and of ensuring that it penetrates into the dust, extinguishing fires with water can be slow. Fire fighting foams, dry chemicals, or vaporising liquids, as fire fighting agents, would have a limited use in the present context.

Gases or liquefied gases may be used as extinguishing agents provided that disturbance of the dust is avoided. Their action is basically the exclusion of air and hence their effectiveness as extinguishing agents depends upon their being present for a sufficient time to allow the dust to cool sufficiently to prevent reignition when the dust is again exposed to air. The agents will thus be particularly effective for a dust which is contained within a relatively gas-tight volume, eg. a bin or silo. The agents have the advantage that they are able to penetrate relatively easily into the dust and can be used in fighting fires in large volumes. However, in such large volumes the heat insulation is good so that natural cooling of the dust is very slow. To ensure complete extinguishing of the dust fire the gas must be maintained for long periods, possibly for days or weeks. Liquefied gas should be introduced to the dust through piping which should penetrate into the dust so that the cooling effect as the liquid boils can then contribute to removing heat from the fire. Gas introduced in liquid form is likely to be a more effective extinguishing agent, but a closer approach to the fire may be needed by operatives in setting up the system.

There is scope for further research into improved methods of applying extinguishing agents to fires in grain, paying particular attention to the large amount of material which may be burning, and difficulty of access.

METHODS OF EXPLOSION PROTECTION

Although the probability of a dust cloud being exposed to a source of ignition can be minimised by good design, it cannot be reduced to zero. Hence methods of explosion protection must be considered. The principal methods are:

Minimising cloud formation
Containment
Separation of units
Relief venting
Inerting
Automatic suppression.

Minimising cloud formation

The energy released in a primary explosion can be reduced by minimising the size of the dust cloud which becomes ignited. Where a large bin or silo is being filled it is better for the dust not to fall freely from a high point but to be introduced gently, preferably at various openings in the side. A silo should not be used as a dust separator in a pneumatic conveying system, the separation should be done separately in a cyclone or other suitable unit, and the dust fed gently to the silo. Plant units should not be too large for the process, so that they never become filled to the design level, leaving large volumes which can contain dust suspensions. Where exhaust ventilation is provided, the dust should be removed from the air as soon as possible, and not be transferred by long ducting to distance central separators.

Containment

The principal of containment is that the plant is sufficiently strong that it can withstand the maximum explosion pressure without damage. As with grain this could be as much as 7 bar (100 lb/in^2). The method of containment is only likely to be attactive on plant of small dimensions and would not be practicable on grain elevators.

Where units such as conveyors are contained for environmental purposes, to prevent spillage of dust to atmosphere, then the containment should be lightweight, but strong enough to withstand wind pressures. In the event of explosion the containment would be disrupted at low pressure and would hinder the development of high flame speeds which could lead to vigorous explosions.

Separation of units

If hazardous plant units can be separated from each other, then, in the event of explosion, a domino effect can be avoided. With grain elevators the various units such as conveyers, bins, must of necessity be in close proximity so that the principle of separation is not readily applied. Separation of buildings containing people, from hazardous plant, is often possible and has not in the past always been given full consideration. With tall plant structures, control rooms and other populated buildings, should be spaced laterally upon the plant by distance at least equal to the height of the plant.

Relief venting

The principle of relief venting is the provision of apertures of the plant or building so that if exposure occurs, and the internal pressure starts to rise, the increase is limited to a predetermined value which is related to the strength of the structure. The maximum pressure obtained depends on the area of the vents and on their distribution. Wherever possible vents should be sited near where sources of ignition are likely to be, and on large plant multiple vents are required.

Information is available on the area of vent required (NFPA 1974, Palmer 1977). The NFPA publication deals with the venting of dust explosions inside vessels and is directly relevant to storage bins and silos, and dust collectors, associated with grain elevators. The publication is based directly on experiments in vessels up to 60 m^3 (2100 ft^3) volume but extrapolation is needed for large volumes. There is a lack of direct information but for large elongated bins (of height/diameter ratio up to 6) there is some merit in requiring half the area of the top of the bin as vent (Palmer 1977).

In bucket elevator legs there is likely always to be a dust cloud, due to the movement of the buckets, and ignition from friction or impact can occur. Explosion vents equal in area to the cross-section of the leg should be provided at the head and the boot and, if the leg is more than 12 m (40 ft) long, at 6 m intervals in the casing. The legs should be mounted outside the building. A similar distribution of vents is desirable on conveyers where although dust may not be permanently in suspension, sufficient may be present within the structure to enable a secondary explosion to develop and to sweep the entire length of the conveyer with increasing violence unless checked by explosion protection measures.

As the action of a relief vent is to expel flame and burning dust, strict attention to the safe disposal of explosion products must be made. They should be directed away from populated areas or vulnerable neighbouring plant. It is undesirable for explosion vents to deliver their discharge into the interior of buildings. Attention is given to this point and to the design of vent covers in NFPA 1974.

Inerting

If inert gas is permanently introduced, during normal working, into dust handling plant then the oxygen concentration can be lowered sufficiently so that explosion will not occur even though a source of ignition may be present. The gases used are frequently nitrogen or carbon dioxide. In general the method is unsuitable for use on grain elevators because of the large volumes involved, the need to provide accurate monitoring of gas compositions at numerous points, and the requirement for an inert gas supply of adequate capacity. Inerting is usually attractive when either the atmosphere in the plant can be recycled with minimal loss or generous supplies of inert gas are freely available as a by-product. In the case of grain elevators this is not the case and inerting is only likely to be attractive for special applications in specific relatively small units.

Automatic suppression

When a dust cloud becomes ignited the flame initially moves relatively slowly, and the incipient rise in pressure can be detected rapidly so that a suppression agent can be injected into the volume to quench the flame before it raises the pressure to a hazardous level. Commercial systems are available and may be attractive for at least parts of grain elevators, eg, elevator legs. Installation of the systems requires expert knowledge and is commissioned from the commercial supplier.

APPLICATION OF RELIEF VENTING

In considering the explosion protection of grain elevators it has become clear that adequate safety cannot be obtained by either attempting to eliminate sources of ignition or by avoiding the presence of dust. Neither requirement can be met fully because both aspects will arise during normal working, but the design of the elevators should as far as possible reduce the likelihood of sources of ignition and dust being present. However, good design in this respect can give only partial protection. For full protection additional measures must be taken and that which is most generally applicable is likely to be relief venting.

For units on the elevator complex which are designed to collect dust, such as filters, cyclones, the venting requirements have been given straightforward coverage (NFPA 1974). In meeting the requirements of the code attention must be paid to the design of the vent cover, and the need for ensuring that flame and combustion products discharged from the vent do not endanger personnel or neighbouring plant. Advice on both aspects is given in the code.

Those parts of the elevator complex concerned with the transport and storage of the grain need particular consideration. In these parts it is the dust which arises from the grain which is most likely to give the major explosion hazard, rather than the grain itself which is of relatively large particle size. During the operation of the elevator the grain dust may either be in suspension, as in a bucket elevator due to the movement of the buckets, or may have settled out but be vulnerable to disturbance, as in conveyers. In both bucket elevators and conveyers, an explosion may propagate throughout the length, either because the dust cloud is present or because the explosion can generate it. Both bucket elevators and conveyers should therefore be protected with vents over their entire length and as a general guide one vent every 6 m (20 ft) is desirable, equal in area to the cross section of the bucket elevator or the conveyer. Such generous venting is particularly desirable where the bucket elevator and conveyer casings are of square or rectangular section, rather than circular, as they will then be structurally weaker. The amount of venting specified is designed to keep explosion pressures, under the worst conditions, down to 0.15 bar (2 lb/in^2) and the casings to the bucket elevators and conveyers should be capable of withstanding this pressure. In the provision of relief venting generally, and with elevators and conveyers in particular, it is important that all parts of the cross section of the units have access to the vent, so that the explosion may be relieved without internal obstruction. Some consideration of explosion venting requirements is given in the NFPA Standard for grain elevators (NFPA 1973). Although relatively a large amount of venting is required for the protection of bucket elevators and conveyers, a greater number of smaller vents, distributed evenly and to the same total area, may be used instead. The smaller vents may be particularly applicable when existing plant is to be modified; with new designs the larger vents may be more economic.

Conveyers which run underground present a particularly difficult problem. Relief venting to atmosphere is essential, and it cannot be to the bins or silos. In existing installations, access to the outside air may have to be provided specially for the vents; in new installations access should be designed in the first considerations. If venting is not provided on underground conveyers the pressure of explosion may be sufficient to dislodge and damage the overlying bins or silos, thus leading to catastrophic loss. Grain elevators with underground conveyers, not fitted with venting, thus present a difficult problem, which needs to be considered on an individual basis.

Bins and silos should be vented at their tops. Difficulty may arise in providing adequate access to atmosphere of vented flame and combustion products. The venting requirements of the silos may then need to be considered together with those of the conveyer. At the present state of knowledge for large volumes, the area of the vent should not be less than half the area of the top of the bin or silo, and preferably larger, particularly if the bin or silo is of non-circular cross section, and structurally weak. With circular sections, design strengths of 0.15 bar (2 lb/in^2) should be obtainable without difficulty but other geometries may present problems. If bucket elevators and conveyers are adequately vented, so that explosion does not damage their structure, then protection of the bins and silos against serious structural damage is obtainable. However if bucket elevators and conveyers are not adequately vented then the bins and silos are also put at risk.

Because elevators are tall structures, burning material vented at high level can fall out over a wide area, depending on wind conditions. As a general guide, horizontal spread could be at least as far as the height of the structure. Similar considerations apply to vent covers which may be dislodged and escape from their restraint. Buildings housing personnel, including control rooms, should preferably be outside the area of fall out. If it is not possible to site the buildings at an appropriate distance, then special strengthening measures, particularly of roofs, may be necessary.

The result of an explosion in a grain elevator, even if it is adequately vented, may be a sustained fire. Such a fire may well be severe because of the size of the explosion flame which initiated it. Fire fighting on this scale requires trained personnel, who will also need protection against smoke and fumes. Untrained personnel should be discouraged from participating.

CONCLUSIONS

1. Consideration of the operation of grain elevators indicates that dust clouds and sources of ignition cannot be eliminated, even though their presence can be minimised by good design and management.

2. Grain dust explosions are therefore to be expected and suitable explosion protection methods should be employed. These include: relief venting, inerting and automatic suppression.

3. The most generally applicable method of explosion protection is relief venting. The amount of venting depends on the design of the unit, bucket elevators and conveyers requiring relatively generous vents. Bins and silos, particularly if of circular section and relatively increased strength, should be vented at their tops.

4. Particular care must be taken to ensure that all regions of a vented enclosure have a direct access to the vent, not obstructed by internal obstacles.

5. Care must be taken to ensure that flames, burning dust and other debris emitted from vents cannot endanger neighbouring buildings and plant. Buildings housing personnel should not be in close proximity to the elevator.

6. Fires and fire fighting in grain elevators can cause serious problems. Final extinguishment of the burning may take a long time, and the smoke and fumes generated by the fire are likely to be hazardous.

7. Further research is needed into the venting requirements of large volumes such as silos, and information is also needed on the distribution and size of volumes of explosible dust suspensions during normal working of grain elevators.

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GRAIN DUST EXPLOSIONS DYNAMICS

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INTRODUCTION

The explosion process that we are specifically interested in is the explosion of grain dust in a grain elevator. Our detailed knowledge of the dynamics of this specific type of explosion is quite scanty at the present time. We do, however, have a reasonable understanding of some of the basic principles of explosion phenomenon in enclosures and portions of this body of knowledge can be applied to the grain dust explosion problem.

Most of the information that we have has been obtained from studies of vapor or gas phase fuel-air explosions in enclosures. We also have an experimental and theoretical understanding of certain aspects of spray/mist explosion dynamics. However, our understanding of the mechanisms involved in dust explosion processes is quite meager at the present time.

The purpose of this paper is to document our current understanding of all types of explosion processes in enclosures. To this end we will first discuss gaseous explosion dynamics, then our current understanding of spray/mist explosions, and finally, dust explosion processes. This final descriptive section will also highlight differences and similarities, either known or expected when gases, mists, or dust mixtures with air explode. A final section contains suggestions for future research.

GASEOUS EXPLOSIONS

If a combustible mixture of a flammable gas and air is distributed uniformly in an enclosure and ignited a number of possible processes can occur. If the entire mixture simply burns at the normal flame velocity the pressure in the entire chamber will be spatially constant but will rise with time. If the chamber is sufficiently strong so that it does not rupture the maximum pressure that can be reached under these conditions lies in the range of 5-8 atmospheres.(1) This pressure is, by itself, sufficiently high to cause extensive damage to any building (or grain elevator) that may suffer such an internal explosion. However, the rate of pressure rise for this type of explosion is generally so slow that if there are sufficient windows or weak wall panels, these will be blown out and the rest of the building will not suffer extensive damage. Venting requirements for this simple type of explosion are quite well understood at the present time.

A second limit type of explosion behavior is detonation wave propagation. All hydrocarbon-air mixtures are known to be susceptible to detonative combustion over a composition range which is generally smaller than the normal flammability range of the fuel. Purely detonative combustion is markedly different than normal flame propagation. Its velocity is in the range of 1500-2500 m/sec while flame velocities are in the range of .3 to 1 m/sec. A detonation wave contains a pressure wave of about 15 to 20 atmospheres, which upon reflection from a solid object can produce up to 60 atm pressure locally. Because of its high velocity the pressure pulse, though large, is of relatively short duration and the pressure in the enclosure is never spatially uniform. Thus the damage pattern for detonative combustion in a building is markedly different than the damage pattern produced by the slow combustion process described above. In general, purely detonative combustion will produce more severe damage to the enclosure and will produce damage that is more highly localized.

In actuality, while occasionally building explosions can be explained by the first "slow burning" mechanism, the purely detonative mode is almost never observed. The reason for this is that to have a purely detonative mode throughout the building one must produce direct initiation of detonation by means of a "hard" ignition source such as a high explosive charge or very high energy, low inductance spark. These types of ignition sources are essentially never present in an accident situation involving the combustion of fuel vapors, mists, or dusts. Instead, in most accident situations the dynamics of the combustion-explosion process lies somewhere between these two limit cases.

Normally, for an explosion to occur after the release of combustibles in the enclosure, a large quantity of the mixture must be in the flammable range when ignition occurs. If too small a quantity is in the flammable range, a fire will result but no damaging explosion will occur. If this condition for explosion is met the ignition source will initially produce a flame propagating at a relatively low velocity. This is because virtually all ignition sources that are found in accidental situations are "soft" and cannot directly produce a detonation wave. Examples are an inductive spark, a hot manifold, an open pilot light, etc., etc. Next, one of two things can happen. Either the flame will not accelerate excessively during the explosion process and the rate of pressure rise will be spatially uniform and relatively slow, or the flame will be caused to accelerate to very high velocities, and even possibly transit to detonation inside the enclosure. The factors which determine which of these two behaviors obtains and indeed exactly how the flame accelerates during an explosion of the second type are fundamentally the location of the ignition point and the geometry and structural strength of all portions of the enclosure. This includes interior details such as the specific location of piping systems, storage racks, process equipment, etc., relative to the point of ignition.

The physical mechanisms by which flame accelerations occur are primarily turbulence generation ahead of the flame due to gas motion induced by the production of low density hot products behind the flame and Taylor instability of the flame front when subjected to an impulsive acceleration in a direction opposite to the propagation direction. The first of these is quite certainly the more important of the two in an accident situation. In an enclosure, acceleration mechanisms can or cannot lead to a detonation of a portion of the mixture and in general it is very difficult to determine whether actual transition to detonation has occurred in an accident situation. This is because, if the acceleration processes have proceeded to the point where the effective burning velocity is very high, the combustion process will generate localized damage similar to that produced by an actual detonation wave. Unfortunately accidents are almost never instrumented, and it is always difficult to confidently describe the exact nature of the combustion-explosion process that has occurred based only on the damage produced.

Experiments have been performed in a few simple geometries and these do illustrate the nature of the acceleration processes. The simplest experiments have been performed in closed tubes with smooth walls and various length-to-diameter (L/D) ratios with ignition at one end. When fuel mixtures are used and L/D is small ($\lesssim 30$), an effective acceleration occurs due to Taylor instability of the flame front.(2) This effect is absent for L/D ratios less than about 3 and increases with increasing L/D. This instability is caused by flame deceleration when the initially spherical flame contacts the side walls and the rate of flame area growth decreases. This deceleration is such that the acceleration vector is in the direction from the heavy fluid (the cold reactants) toward the light fluid (the hot product gases). Under these conditions the flame surface is dynamically unstable and convolutes with time, producing a larger surface area and therefore larger effective conversion rate.

In longer straight tubes, L/D $\gtrsim 30$, Taylor instability occurs at first but later the flow generated ahead of the flame by the expansion of the hot products causes a boundary layer to grow on the walls. When this boundary layer becomes turbulent the flame starts to propagate along the walls at high velocity and eventually produces a conical flame shape which causes the effective flame velocity to become very high. This, in turn, causes the flow velocity ahead of the flame to increase further. Furthermore, when this happens the pressure rises and a strong shock wave is formed somewhere ahead of the flame. Eventually if the tube is long enough the flame acceleration process will proceed until autoignition occurs somewhere between the shock and the flame. This in turn quickly causes a detonation to propagate through the rest of the tube. Oppenheim and his coworkers(3-5) have studied this process extensively in the hydrogen-oxygen system.

It has been observed that the flame acceleration process in tubes is greatly enhanced by any roughness of the tube walls. In fact, sufficient roughness or confinement by means of orifices or grids, etc., can cause the almost immediate formation of a detonation wave.

In a recent series of experiments, Wagner and coworkers[6] have ignited a flame at the center of a spherical grid whose openings were large enough to allow flame passage. They observed that the flame accelerated to a new, higher velocity after passage through the grid and that the ratio of the flame velocity after passage to that observed inside the grid increased with the maximum Reynold's number of the flow past the grid and asymptotically approached 6 at high Reynold's numbers.

Even more recently, Knystautas _et al._(7) have shown that obstacles that produce large scale vortices or folding of the flow can cause direct shockless transition to detonation in oxygen enriched stoichiometric fuel-air mixtures. This is very new work, but its implication to accident scenarios involving explosions could possibly be profound because it currently represents the most viable mechanism of transition to detonation in an accident situation.

Venting of the enclosure also has a large effect on the explosion process. There has been a considerable amount of work done in this area and recently a rather comprehensive theory for gas phase venting for chambers with a low L/D ratio has been presented by Bradley and Mitchelson.(8) In a follow-up paper(9) they survey most of the experimental work that is extant and compare it to their theoretical predictions. The comparison is reasonably good considering the large variation in experimental configurations found in the literature. They found that the two parameters that can be used to correlate venting behavior in chambers with a low L/D ratio are the normal burning velocity divided by a reference velocity of sound of the gas ahead of the flame ($\bar{S} = S_u/a_o$) and a discharge coefficient multiplied by the vent area and divided by the surface area of the enclosure ($\bar{A} = C_D A_V/A_S$).

HETEROGENEOUS CASE - COMBUSTIBLE SPRAYS AND DUSTS

A. Flame Propagation

In contrast to the all-gaseous case, which, as noted above, has been the subject of extensive analytical and systematic experimental studies, heterogeneous combustion represents a much more formidable problem, particularly in the case of dusts. With the condensed species present, the type of fuel as well as size of the particles will be important. In the usual cases of relatively low flame propagation rates in sprays, heat conduction from the reaction zone vaporizes the fuel which then mixes with the air and burns. In the case of dusts, the shape of the particle, the moisture content, and the concentration of volatiles are all important. The heating of the particles in this case will lead to the onset of surface reactions and self-heating, driving out of the volatiles, and/or change of phase.

Many of the general characteristics of flame propagation in gases, as discussed in the previous section, carry over to the heterogeneous case. However, there are mechanistic differences and the necessity of effecting a change in phase of the fuel before combustion can occur dictates that the rates of reaction, in general, will be slower. This leads to greater flame thicknesses and to lower flame speeds. For dusts the rates of reaction are obviously very dependent on total surface area of the particles. This likely accounts for the profound influence of particle size that has been noted for the case of burning dusts. This is because, for the same concentration of dusts (grams per liter), smaller particles will have greater total surface area. This undoubtedly also accounts for the fact that relatively high concentrations of dust are required for ignition and are more explosive. Similarly, flames can propagate in dusts at equivalence ratios which are much higher than the limiting equivalence ratio for gaseous flames. Typically, the upper limit for gaseous fuels is $\phi = 3.3$ whereas for sprays and dusts it can be as large as 10.

There are two other important differences between spray droplet/dust flames on the one hand and systems based on gaseous fuels. In the first place, it would be essentially impossible to work in an environment that contained a combustible spray droplet/dust-air mixture. Particle concentrations must be so high for these systems to support combustion that the optical extinction coefficient is such that you "could not see your hand in front of your face." This is in contrast with most lower hydrocarbons. One can, for example, breath a 6% methane-air mixture with no ill effects - yet it is explosive. Secondly, because of the high density of a solid or liquid phase fuel, in a combustible mixture with air the volume fraction of the fuel is about 10^{-5} cc/cc. Thus dust can be dispersed into the air without displacing a large quantity of air. Both of these facts lead one to the conclusion that the real fuel source in grain dust explosions is not the dust that is in the air during normal operation of the elevator but the dust that has accumulated on interior surfaces.

Another area of difference from the gas case, is the importance of radiation to flame propagation rates in dusts. Cassel(10) and Bhaduri and Bandyopadhyaz(11) have shown (at least in the combustion of coal) that radiation from the burning dust to the fresh dust is an important mechanism in preparing the particles for combustion. This facet, along with the greater reactive zone thicknesses, tends to demand larger scale research apparatus for meaningful studies, or at least inclusion of these effects in evaluation of the data.

B. Accelerating Flames -- Detonation

As was brought out in the discussion of the gaseous case, flames in enclosures act like pistons and can accelerate and cause the gas ahead of the flame to be set in motion. This motion produces other effects that serve to reenforce the strengthening wave and cause quite high velocities to be produced. In the case of gases, the wall boundary layers act to wrinkle the flame and increase turbulence levels. The effect is to increase the rate at which the reactants are consumed and, in many cases, may produce shock waves followed by transition to detonation. Such phenomena are very well known and understood by researchers in gaseous explosions and, of course, lead to very high and localized pressures.

In the case of flame propagation through a cloud of liquid drops, the high gas velocities generated can lead to another contributing accelerating mechanism; namely, that of aerodynamic shattering of the drops. The inertia of the drops leads to a significant velocity difference between the surrounding gas and the drops. This relative dynamic pressure causes the drops to rapidly break up into a microspray with consequent rapid vaporization and chemical reaction. This effect enhances the acceleration process and full detonation may be realized. Dabora, Ragland, and Nicholls(12) studied heterogeneous detonation (liquid fuel drops) and showed that aerodynamic shattering was the rate controlling step; that is, vaporization of the microspray and chemical reactions were fast by comparison.

The problem of flame acceleration in dusts is probably best documented by experiences in galleries in the study of coal mine explosions. In this case, the elevated gas velocities produced by the advancing flame cause the dust to be dislodged from the floor and walls and to be distributed across the chamber. This effect is highly favorable to further flame acceleration and strengthening and substantial increases in pressures can be obtained. Examples of this behavior are indicated in the studies of Richmond and Liebman,(13) Rae,(14) and Palmer and Tonkin.(15) Wojcicki and Zalesinski(16) have reported on the attainment of detonation in coal dust-oxygen mixtures. They concluded that the volatiles played a major role and initiated the chemical reaction. Fox and Nicholls(17) ignited small magnesium particles with shock waves. They showed that the high temperature, high velocity gases behind the shock led to very high rates of heat transfer to the particle. Presumably this could account for high flame speeds and, possibly, detonation in dust mixtures.

Finally, there is the possibility that a localized very rapid release of energy in a combustible medium may lead to the direct initiation of detonation. Nicholls, Sichel, Fry, and Glass(18) have demonstrated this by passing a cylindrical shock wave into a cloud of liquid kerosene drops (384 μm diameter) and air. Presumably, dusts of much smaller particle size could also support a detonation, although controlled studies of this aspect of dust-air detonations are almost nonexistent.(19)

RESEARCH NEEDS

The hazards associated with the handling and storage of large quantities of grain dust are difficult to bypass in view of the primary function. Obviously one fundamental step towards avoiding an explosion is to ensure that no ignition source exists, which is easier said than done. A second step, but probably not a practical one, is to continuously purge the elevator with an inert gas. Steps beyond these two means may not be so obvious or direct but, rather, would have to depend on some of the ignition and combustion characteristics of the various dusts. This information is, in general not readily available and there exists a distinct need for well controlled research studies of this problem. The results would not only be pertinent to grain elevators but to a whole myriad of dust problems.

As was brought out earlier, the nature of gases has made it possible to study gaseous ignition and combustion extensively and in a well controlled fashion, analytically as well as experimentally. The same might be said for the case of the combustion of liquids, but to a lesser extent. However, when it comes to dusts, the level of understanding is much lower. The problem is much more difficult and the relative influence of the various competing factors has not been identified. A fair amount of testing has been done (such as determination of explosibility index) in order to meet the various demands. However, relatively few well controlled studies on a research level have been conducted. This is not surprising when one considers the many factors and complications that arise. The ignition and combustion processes are known to depend on the particular dust, the size and shape of the particles, the volatiles present, and the moisture content. Simultaneously, one must consider the influence of the concentration in a distributed cloud, the "layer" self-heating effect, the influence of electrical charge buildup, the presence of heated surfaces, and probably some other effects. Further, in view of the nature of dusts, it is difficult to set up experiments to isolate the various factors and analytical studies become, of necessity, very complicated.

We believe there is a real need for systematic research studies in this important combustion area. Further, the studies should be of a fundamental nature and hence should probably be supported by federal funds. The studies should not be restricted to testing but should be detailed research investigations. Today there are a variety of experimental techniques that could be employed. Hand in hand with this are the availability of advanced instrumentation systems. On the analytical side, a comprehensive formulation of the problem along with the experimental studies and the availability of extensive computing capability should allow much information to be gained as to the influence of the many factors cited above. This kind of knowledge would be valuable as a guidance for the appropriate steps to reduce the explosion hazard.

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CIBA-GEIGY LIMITED BASLE SWITZERLAND

GAS, VAPOUR AND DUST EXPLOSIONS

FUNDAMENTALS, PREVENTION, CONTROL

Contribution prepared for the
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SUMMARY

The course of gas, vapour and dust explosions in closed vessels and in pipelines is described, including the explosion behaviour of the particularly hazardous "Hybrid Mixtures", i.e. dust dispersions in air that contains small quantities of a flammable gas or vapour. For explosions within closed or relieved vessels, the influence of volume on the violence of the explosion is characterised by the Cubic Law; the validity of this law has been confirmed by a large number of test explosions on a technical scale. The Cubic Law permits the scale-up of explosion pressure relief devices and of explosion suppression systems from tests in 20 litre and in 1 m^3 explosion chambers. The full range of preventive and protective measures against gas, vapour and dust explosion is discussed: Inertisation, pressure resistant or pressure shock resistant construction, explosion relief, explosion suppression, barrier devices. Conclusions for grain elevators are drawn.

CONTENTS

PREFACE

The task force on Explosion Research of CIBA-GEIGY Limited, headed by Dr. W. Bartknecht, studies the course of gas, vapour and dust explosions and develops protective devices to prevent or control explosions. The following facilities are at its disposal:

Explosion research laboratory

Cylindrical test chambers of 7 l, 30 l and 1 m^3

Spherical test chambers of 5 l and 20 l

Ignition equipment to activate ignition energies from 0,1 mJ to 10'000 J

Electronics to monitor explosion pressure, rate of pressure rise, gas concentrations, flame velocities etc.

Open air test site

The test site is used to confirm laboratory results, e.g. mathematical interrelationships, design formula etc, on a technical scale and to test pressure resistant enclosures, relief devices, explosion suppression and barrier equipment, etc, under explosion conditions on a 1:1 scale.

The taks force works primarily for the needs of the CIBA-GEIGY group of companies. Research, development and consulting for other companies is done on a limited scale.

1. INTRODUCTION

In the years 1960 - 1972, insurance companies have paid compensations for more than 4000 dust explosions that occurred in the Federal Republic of Germany and its neighbour countries. This means that, on average, there was one explosion on every working day. These figures stand for a considerable number of personal injuries and tremendous material losses.

It is very well known that flammable gases and vapours can form explosive mixtures with air and, when ignited, explode with devastating effects (fig. 1).

Fig. 1: Explosion of carbon monoxide/air mixture in a large electro filter

It is not so well known that the dusts of most combustible solids, when whirled up in air and ignited, can explode with even more severe effects (fig. 2). Table 1 compares the relative explosion frequency of various dusts. Thus, dusts of wood, foodstuffs and fodders show the highest frequency of dust explosions. Table 2 indicates the type of equipment in these two industries within which the explosions occurred.

Fig. 2: Production room of a chip board factory after a wood dust explosion

Table 1: Relative explosion frequency of various dusts

Nature of dust	rel. frequency (%)
Wood	34,5
Food and fodder (incl. grain)	28,2
Plastics	12,6
Coal and peat	10,9
Metals	10,4
others	3,5

Table 2: Type of equipment within which dust explosions occurred

Industry	Equipment	rel. frequency (%)
Wood	Silos and bunkers	45,0
	Filters	13,8
	Dryers	11,7
	Furnaces	11,6
	Grinding machines	8,3
	others	10,0
Foodstuffs and fodders	Mills	28,6
	Silos	24,5
	Conveyers and elevators	22,5
	Dryers	10,2
	others	14,3

It appears that dust explosions are most likely to occur in silos and bunkers, mills, conveyors and elevators, filters.

Industry - supported by authorities - has been induced by this fact to investigate systematically the explosion behaviour of flammable gases and vapours and of combustible dusts and to develop safety measures either to prevent explosions at all or to control their effects. The goal is to maintain a high level of safety and optimal economy of operations.

However, the application of protective measures must be based on a thorough

evaluation of effectiveness.

A basic requirement for such evaluations is the possibility to describe and characterise the course of explosions by certain explosion data that will be discussed in the following sections.

2. THE COURSE OF EXPLOSIONS

2.1 Explosions within closed vessels

2.11 Gas explosions

The explosion data that will be used to characterize the course of explosions of flammable gases and vapours mixed with air have been determined by systematic research for which explosion chambers from some 10 cm^3 to 60 m^3 in size were used.

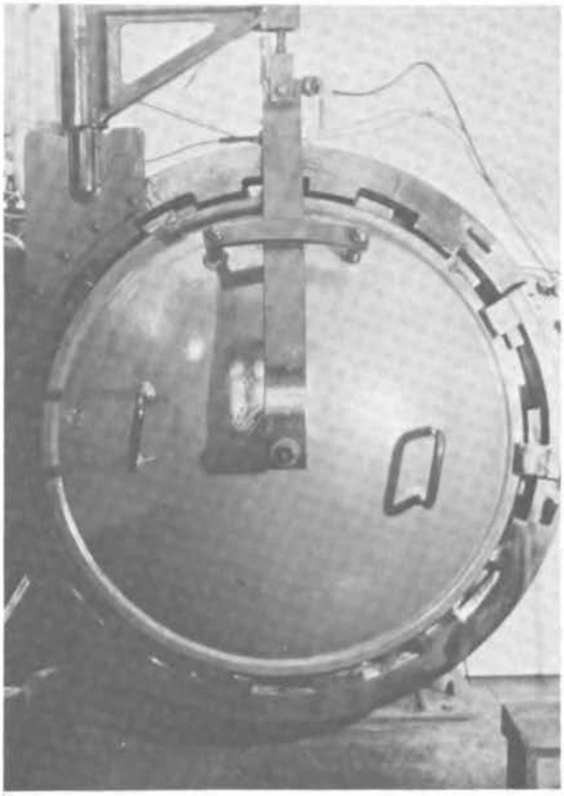


Fig. 3: 1 m^3 explosion chamber for basic explosion research

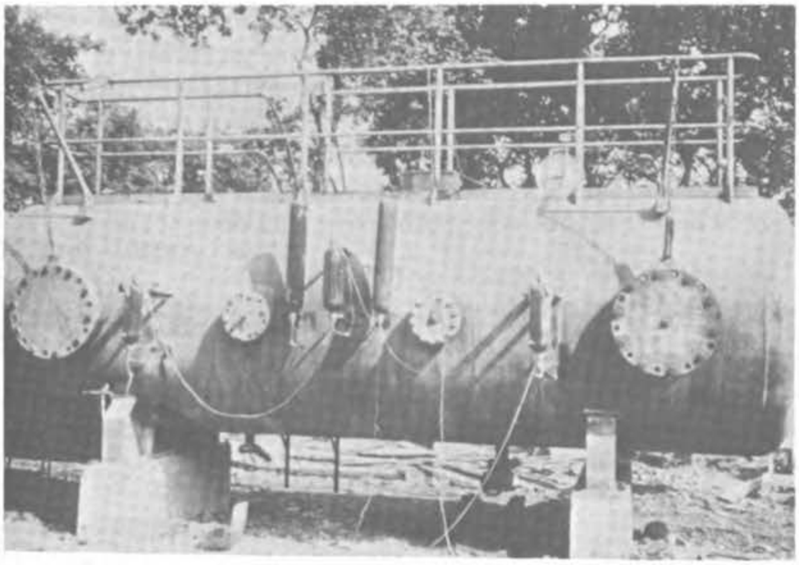


Fig. 4: 20 m^3 explosion chamber for basic explosion research

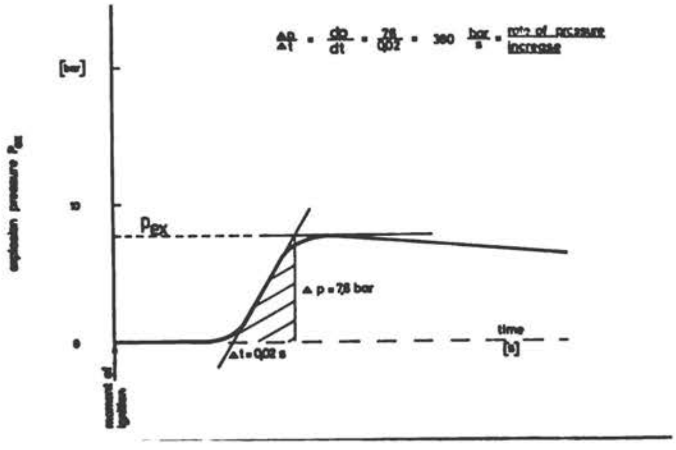


Fig. 5: Determination of the rate of pressure rise dp/dt of a gas explosion (any concentration)

Fig. 5 shows the typical course of pressure vs. time of a gas explosion (gas/air-mixture, any concentration within the explosive range) in a closed vessel of a certain volume. The explosion is characterized, on one hand, by the explosion pressure P_{ex} generated at this particular concentration, and on the other hand by the pressure increase per unit of time dp/dt, characterized by the slope of a tangent through the point of inflexion of the pressure/time course. The maximum values of P_{ex} and dp/dt are determined by systematic tests over a wide range of concentrations (fig. 6) and are defined as

maximum explosion pressure P_{max} and

maximum rate of pressure rise $(^{dp}/_{dt})_{max}$

Maximum values for these data are found in a concentration range close to stoichiometric proportions.

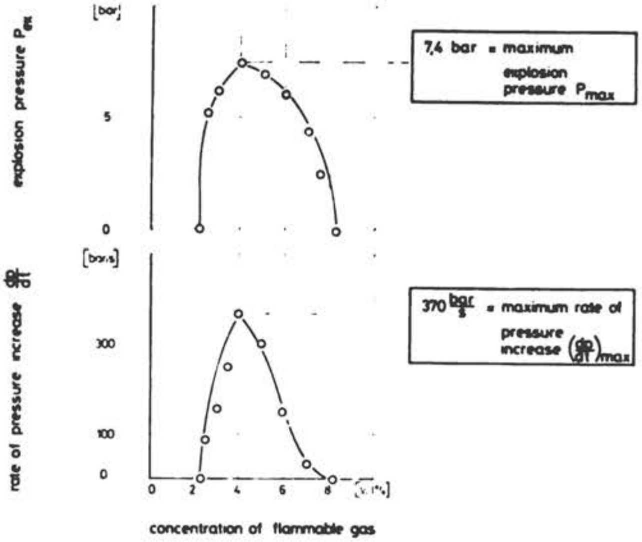


Fig. 6: Determination of maximum values of the explosion data of a flammable gas

If, for a given explosive gas mixture and constant conditions of concentration, pressure and ignition, the volume of the explosion chamber is changed, the maximum explosion pressure P_{max} will remain constant, but the maximum rate of pressure rise $(^{dp}/_{dt})_{max}$ will change according to the following equation:

$$(^{dp}/_{dt})_{max} \cdot V^{1/3} = \text{const.} = K_G \qquad \text{(G stands for \underline{G}as)}$$

Thus, the maximum rate of pressure rise will decrease with increasing volume. This relation is known as the "Cubic Law", and K_G ($bar \cdot m \cdot s^{-1}$) is a material constant, characterising the explosion behaviour of the gas in question at "optimum" concentration (i.e. concentration giving highest readings). The exact validity of the Cubic Law for vessels of similar shape (more or less cubic, i.e. diameter to length ratio approx. 1:1) has been proven by series of systematic tests in volumes ranging from 1 l to 60 m^3. The minimum volume for reliable determination of explosion data of flammable gases and vapours is V = 1 l.

Table 3 gives the values of P_{max} and K_G of three typical gases, determined in a spherical test vessel under the following experimental conditions:

a) no turbulence at the moment the ignition source is activated

b) initiation of the explosion by a "permanent" spark gap (E ≈ 10 J, comparable to an automobil spark plug)

Table 3: Explosion data of typical gases (spherical chamber)
Permanent spark gap: E ≈ 10 J

Gas	P_{max} (bar)	K_G ($bar \cdot m \cdot s^{-1}$)
Methane	7.4	64
Propane	7.9	96
Hydrogen	6.9	659

Explosion data - especially K_G - are influenced by the nature and the energy output of the ignition source. This is shown in table 4 on the example of propane.

Table 4: Influence of the nature and the energy output of the ignition source on the explosion data of propane
Ignition of non-turbulent mixtures

Nature of ignition source	E (J)	P_{max} (bar)	K_G (bar·m·s^{-1})
Permanent spark gap	~ 10	7.9	96
Condenser discharge	0,0005 - 0,01	8.5	216
Pyrotechnical ignitor	10000	8.5	280

Weak (low energy) condenser discharges with an energy output just above the lowest value for the minimum ignition energy of propane yield K_G values nearly as high as those produced by the extremely high ignition energy of pyrotechnical ignitors. The comparatively high ignition energy of the permanent spark gap leads to rather low values of K_G.

The explosion data discussed above will change in proportion to the initial pressure at which the explosion is initiated; fig. 7. If the initial pressure is reduced below atmospheric pressure, the values shown above will decrease accordingly until, at a certain limit, propagation of the explosion reaction is no longer possible. For propane/air-mixtures, this limit is in the order of some 10 mbar.

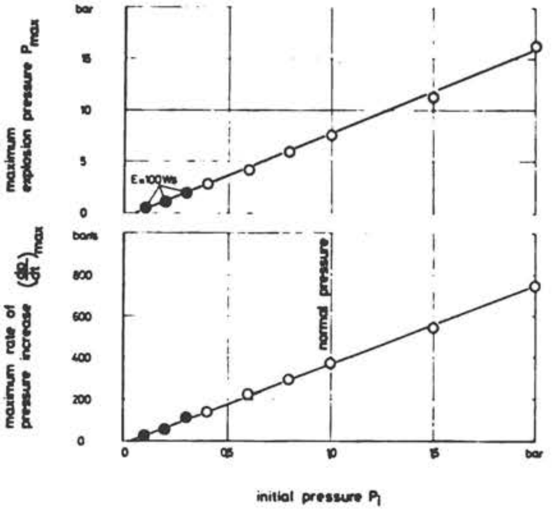


Fig. 7: Influence of the initial pressure on the explosion data of propane
7 l test chamber, E ≈ 10 J

The considerations presented so far apply to gas mixtures that are not in a turbulent state at the moment when the ignition source is activated. Under conditions of turbulence, yet unburned gas comes much faster into contact with the flames emanating from the center of ignition. Thereby, the effects of pressure and of explosion violence are amplified. Fig. 8 shows the percentage increase of the maximum values for explosion data of flammable gases. The increase is linear, in proportion to the inverse value of K_G.

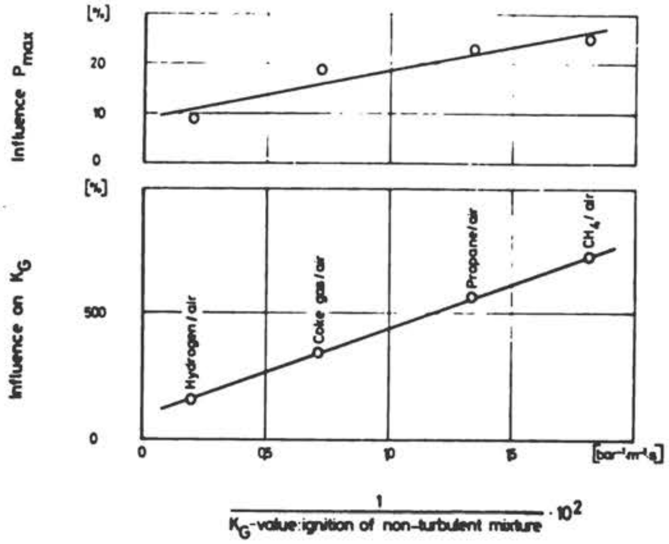


Fig. 8: Percentage increase of maximum values of explosion data of combustible gases, caused by high turbulence
E ≈ 10 J

The influence of turbulence on the course of explosion is much more pronounced for gases with a low normal burning velocity (i.e. methane, propane) than for gases with a high normal burning velocity (i.e. hydrogen).

A special situation exists when vessels are interconnected by pipelines so that an explosion can propagate from one vessel to an other one (fig. 9). Extraordinary high peak pressures must be expected if an explosion starts in a larger vessel and then propagates through a pipeline into a smaller one. This is illustrated by the figures given in table 5.

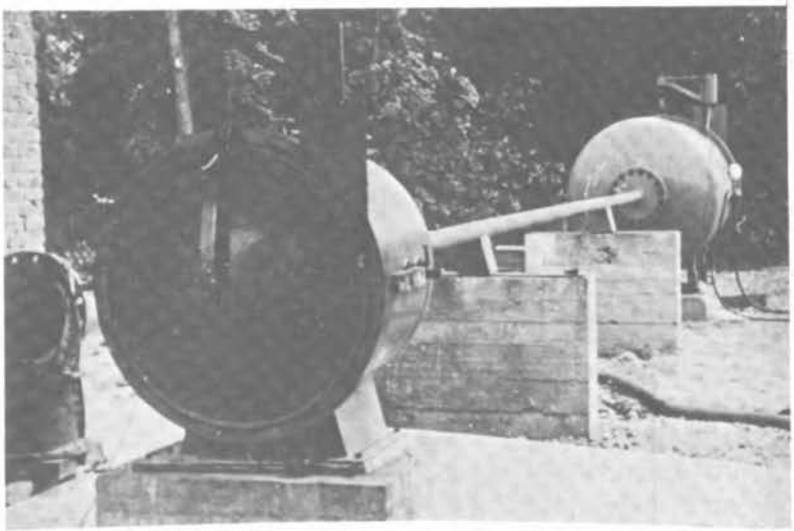


Fig. 9: 5 m^3 vessel (where ignition is initiated) connected with pipeline to 1 m^3 vessel (secondary vessel)

The increase of the explosion pressure in the secondary vessel is caused by the fact that the flame jet propagating through the pipeline into the secondary vessel encounters an explosive mixture that is already precompressed to a certain degree, the explosion in the primary vessel having forced unburned mixture and combustion product to flow into the secondary vessel.

Table 5: Explosion pressure in secondary vessel V_2, connected to primary (ignition) vessel V_1 by pipeline

V_1 (m^3)	Diameter of pipeline (mm)	combustible gas	V_2 (m^3)	P_{max}, V_2 (bar)
0,05	45	propane	0,005	18,5
0,225			0,005	25,0
0,05	45	hydrogen	0,005	23,5
0,225			0,005	31,0
5,0	400	propane	1,0	25,0
		hydrogen		18,0

The lowest minimum ignition energy of flammable gases, i.e. the lowest quantity of energy just sufficient to ignite the most easily ignitable gas/air-mixture is, for most gases, below 1 mJ, as can be derived from literature (table 6).

Table 6: Lowest minimum ignition energy $(E_M)_{min}$ of gases

Gas	$(E_M)_{min}$ (mJ)
Methane	0,30
Propane	0,26
Hydrogen	0,011

2.12 Combustible Dusts

The interrelationships found for gases can also be applied to combustible dusts suspended in air. A prerequisite for reproducible test results is the application of a standardised dust dispersion and ignition procedure. A suitable dust dispersion method was developed in the Federal Republic of Germany approx. 13 years ago: Dust is dispersed from pressurised storage cylinders (volume 5,4 l, gas pressure 20 bar) through suitable nozzles. A nearly homogenous dispersion is obtained (fig. 10). Ignition by a sufficiently powerful ignition source is activated after emptying the storage cylinders (fig. 11). This method was applied also for the work reported in this paper.

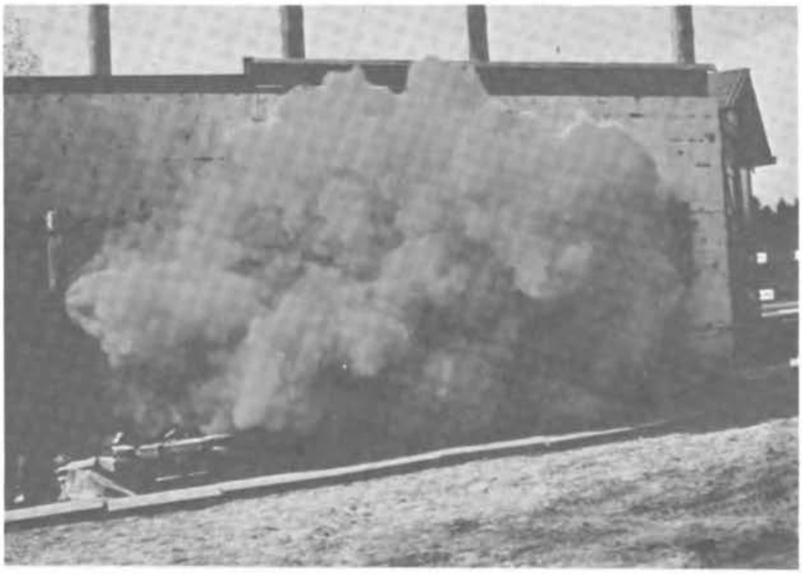


Fig. 10: Preparation of a dispersion of pigment dust in air (4 kg of pigment)

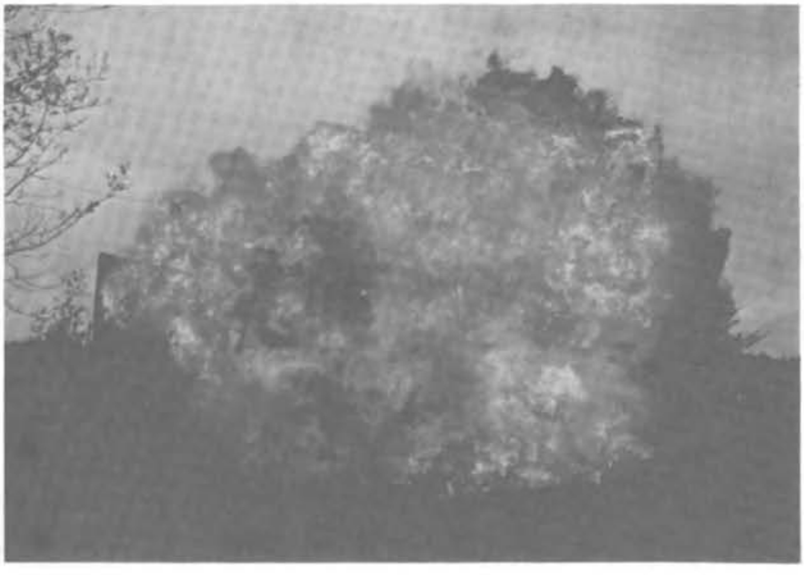


Fig. 11: Unconfined explosion of the dust cloud shown in fig. 10

Also in the case of dusts, the course of a fuel/air-mixture of optimum concentration taking place in a given enclosure is characterised by

the maximum explosion pressure P_{max}

the maximum pressure increase per unit of time $(dp/dt)_{max}$

These data, like the ones for gases, are determined by systematic series of tests over a wide concentration range (fig. 12).

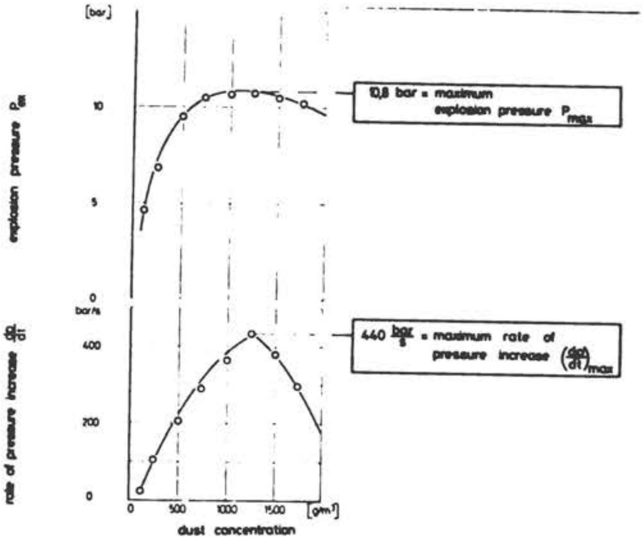


Fig. 12: Determination of maximum values of explosion data of a combustible dust

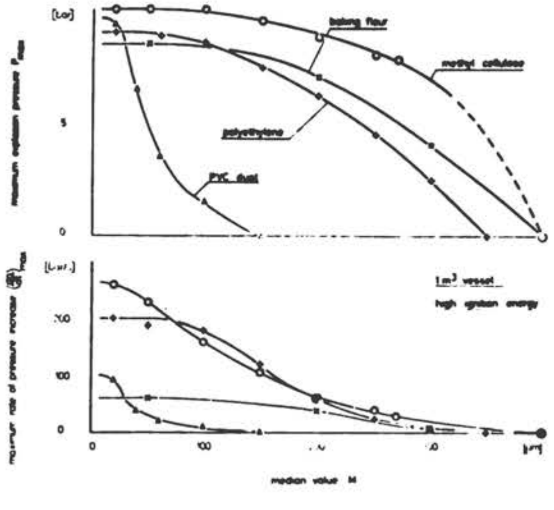


Fig. 13: Influence of particle size on explosion data of combustible dusts; 1 m³ explosion chamber

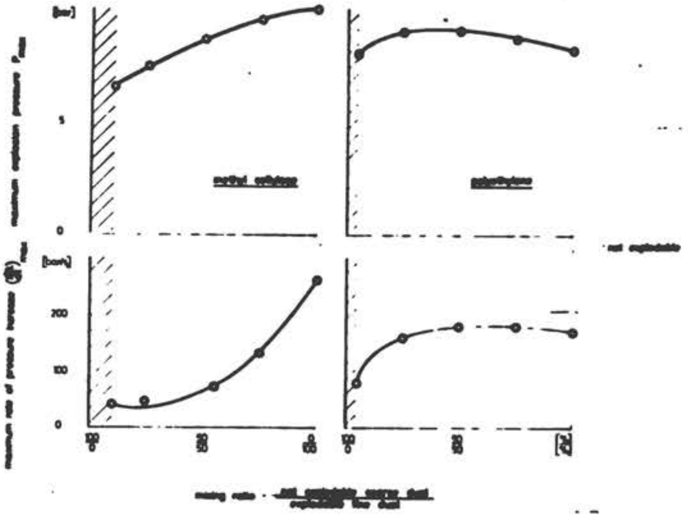


Fig. 14: Explosion data of mixtures of non-explosive coarse dust with explosive fines; 1 m^3 explosion chamber

Particle size, characterised by the Median Value - i.e. the 50% value of the particle size distribution curve - strongly influences the explosion data (fig. 13). A fine dust explodes with greater violence than a coarse one. Therefore, planning and design of protective measures against dust explosions must be based on explosion data measured for the fines of a given dust. "Dusts" with a particle size above approx. 400 µm cannot be initiated to explode even with high energy ignition sources. However, in industrial operations, increasing the particle size above this value cannot be regarded as a protective measure since even a small percentage of fines - e.g. generated by abrasion - may cause the coarse dust to become explosive when dispersed in air (fig. 14).

Humidity also has an influence on the explosion data. In general, a moisture content of at least 50% would be required to prevent dust explosions. Moisture contents up to 10% have little influence on the course of dust explosions.

Also for dispersions of combustible dusts, there is a practically linear relationship between the explosion data and the initial pressure prevailing at the moment the ignition source is activated.

The "Cubic Law", as explained for gases, is also valid for dust dispersions:

$$(dp/dt)_{max} \cdot V^{1/3} = K_{St}$$ (St stands for Staub, i.e. dust)

This was confirmed by comprehensive test series in volumes from 20 l to 60 m^3. However, due to the influential factors described above, the explosion behaviour of different grades of dusts bearing the same name may be quite different from each other. Therefore, in table 7, typical ranges of the explosion data of some dusts are given.

Table 7: Explosion data (ranges) of combustible dusts

Nature of dusts	P_{max} (bar)	K_{St} ($bar \cdot m \cdot s^{-1}$)
Coal dusts	7,8 - 8,0	60 - 97
Grain dusts	8,6 - 9,3	98 - 112
Polyethylene dusts	1,3 - 7,9	4 - 120
PVC dusts	7,5 - 9,6	37 - 168
Epoxy resin dusts	5,3 - 10,0	53 - 168
Flour	7,9 - 10,5	80 - 192
Organic pigment dusts	6,5 - 10,7	28 - 344
Aluminim dusts	6,5 - 13,0	16 - 1900

For most dusts, the values given in table 7 are - within the range of measuring accuracy - independent of the nature of the ignition source and of the energy output of the source, if one of the following sources is applied:

a) Condenser discharge with an energy output above the lowest minimum ignition energy of the dust in question, i.e. energy output (generally) in the order of mJ.

b) Pyrotechnical ignitor with an energy output of ~ 10'000 J.

c) Lump of smoldering dust.

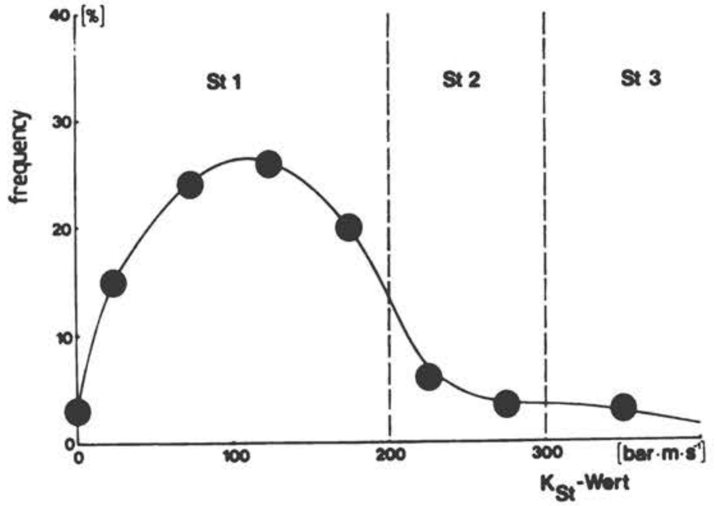
However, if a spark gap ($E \approx 10$ J) is used as ignition source, the values found for K_{St} may be upto 60% lower than those observed when using one of the afore mentioned ignition sources a), b) or c). Test results obtained with spark gap ignition will lead to an underestimation of the possible explosion violence of combustible dusts. Thus, also in this respect, the behaviour of dusts is comparable to that of gases.

Since an extremely large number of combustible dusts are handled in industrial operations, it proved necessary to classify them into dust explosion hazard classes, and to develop and design preventive and protective measures for the different hazard classes:

Table 8: Definition of dust explosion classes

Dust explosion class	K_{St} ($bar \cdot m \cdot s^{-1}$)
St 0	0
St 1	> 0 - 200
St 2	201 - 300
St 3	> 300

Systematic determination of the explosion data of more than 600 combustible dusts being handled in a chemical firm revealed the percentage distribution shown in fig. 15.



<u>Fig. 15</u>: Number of dusts vs·K_{St}-values of combustible dusts handled in one large chemical firm

It seems that the majority of dusts fall into class St 1.

The minimum ignition energy of a dust is strongly influenced by its concentration, as shown in fig. 16. The lowest values for the minimum ignition energy are observed at concentrations that will give the highest explosion pressure. So far, the lowest minimum ignition energy has been determined by means of condenser discharge ignition in the 1 m^3 test chamber for 38 different dusts. Table 9 shows the percentage distribution of these dusts into different ranges of minimum ignition energy.

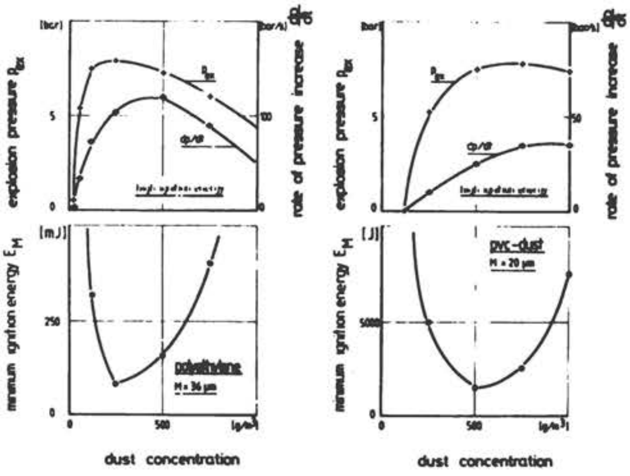


Fig. 16: Minimum ignition energy vs. dust concentration

Table 9: Lowest minimum ignition energy of combustible dusts, 1 m^3 test chamber, condenser discharge

$(E_M)_{min}$ (mJ)	1 - <10	10 - <100	100 - <1000	>1000
Number of dusts	10	8	8	12
Percentage	26	21	21	32

A nearly even distribution over these categories was found. Noteworthy is the fact that 26% of the dusts tested have a lowest minimum ignition energy in the range below 10 mJ. These dusts (e.g. 2-naphtol, magnesium stearate, stabilising agents) are highly ignitable, their lowest minimum ignition energy is only one order of magnitude higher than that of flammable gases. - The highest minimum ignition energy found so far was observed with fine dust of pure PVC. This material required an ignition energy in the order of 1500 J.

The minimum volume of an explosion chamber for reliable determination of explosion data of combustible dusts is 20 l (fig. 17). This conclusion was derived from the results of more than 6000 test explosions, carried out with more than 60 different dusts under different ignition conditions in test apparatus of various sizes (fig. 18).

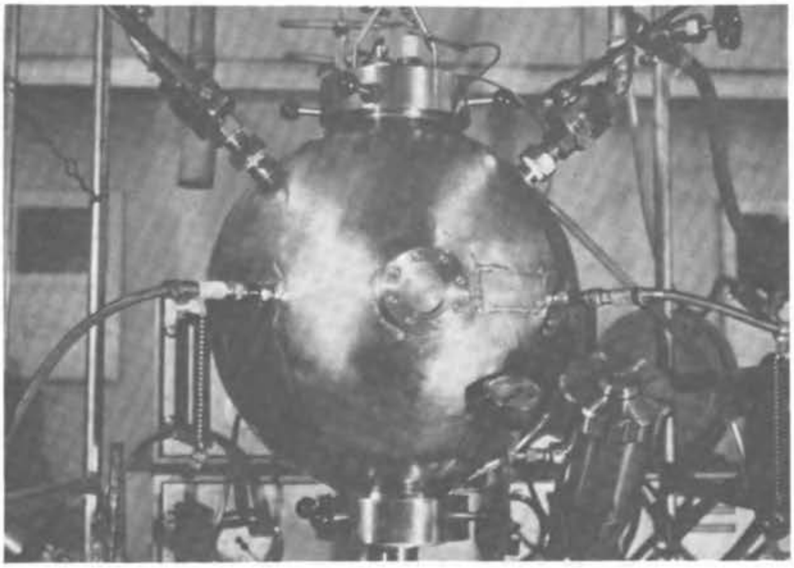


Fig. 17: Laboratory equipment: 20 l sphere for dust explosion tests

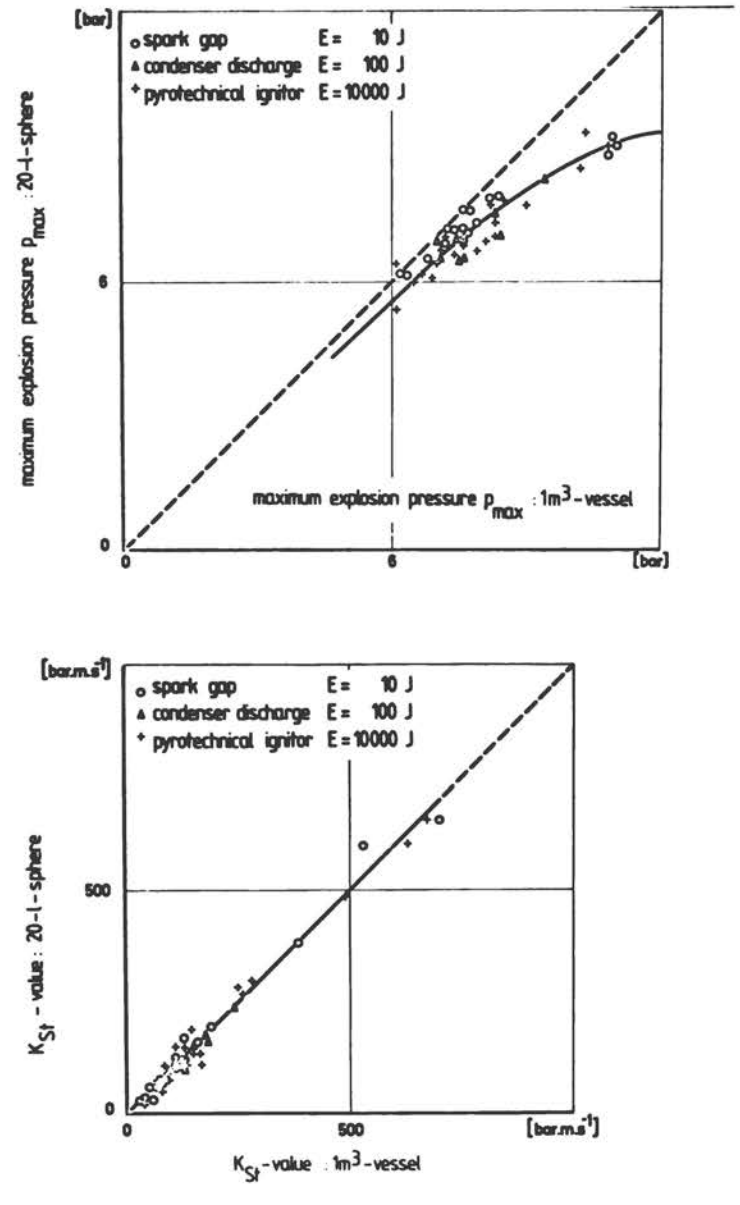


Fig. 18: Comparison of dust explosion data determined in the 20 l sphere and in the 1 m^3 explosion chamber

The values measured for the maximum explosion pressure in the 20 l sphere have to be converted to 1 m^3-values by means of a conversion graph. The K_{St}-values measured in the 20 l sphere and in the 1 m^3 chamber are the same.

If laboratory apparatus with a volume of less than 20 litres are used, correlation with results obtained in larger volumes becomes uncertain (fig. 19) and the K_{St}-values seem to level off to a "ceiling value" dictated by the equipment.

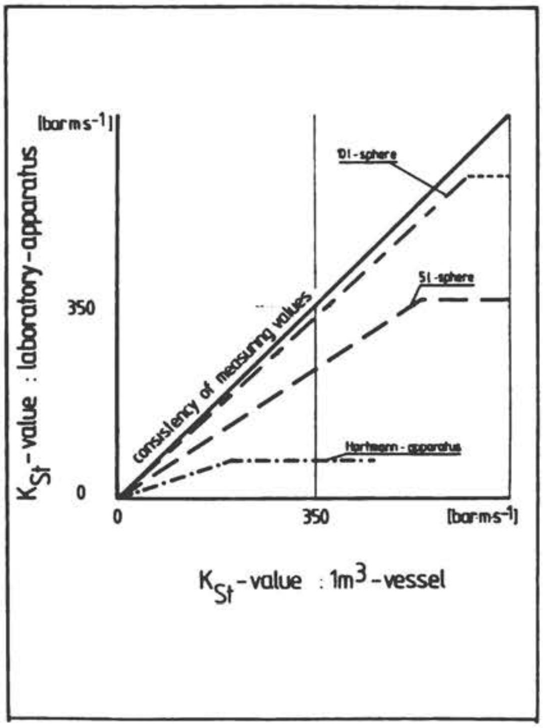


Fig. 19: Comparison of K_{St}-values measured in laboratory apparatus of different volumes with values determined in the 1 m³ test chamber. Spark gap ignition E ≈ 10 J

Data determined in the well known "Hartmann Bomb" compare extremely unfavourably with results obtained in larger apparatus, due to the small volume of this device and also the wide scatter of results. There are no constant conversion factors that would permit a conversion of "Hartmann Bomb" results to larger volumes, i.e. to use them as a base for the design of safety devices (fig. 20). "Hartmann Bomb"-data may enable the dust explosion expert to draw certain qualitative conclusions with regard to the explosion behaviour of a dust.

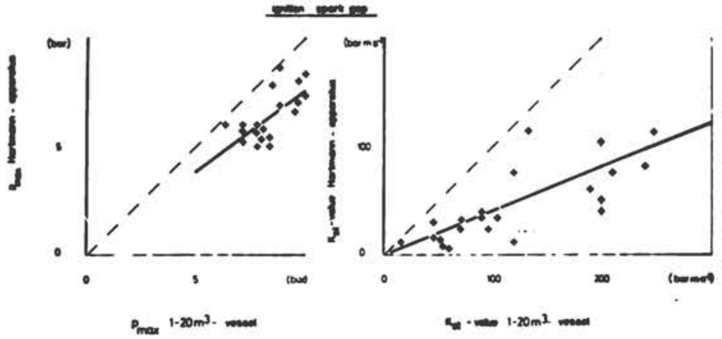


Fig. 20: Comparison of explosion data determined in the Hartmann bomb and in the 1 m^3 explosion chamber. Spark gap ignition E $\approx$ 10 J

2.13 Hybrid mixtures

Hybrid mixtures, i.e. dust dispersions in air that contain a certain quantity of flammable gases or vapours, have gained much importance in connection with numerous explosion incidents in industry in the recent past. Research carried out so far clearly indicates that the presence of such mixtures in industrial plants constitutes a particular hazard. So far, the following facts have been established:

a) A non-explosive dispersion of combustible dust in air and a non-explosive mixture of a flammable gas or vapour in air can form an explosive mixture when combined.

This can lead to the following consequences, illustrated in fig. 21 on the example of PVC:

b) Admixture of a small quantity of flammable gas or vapour to an explosive dust dispersion may cause a marked increase of the explosion data.

c) The dispersion of a combustible dust that is too coarse to be explosive, may be rendered explosive by admixture of a small quantity of flammable gas or vapour.

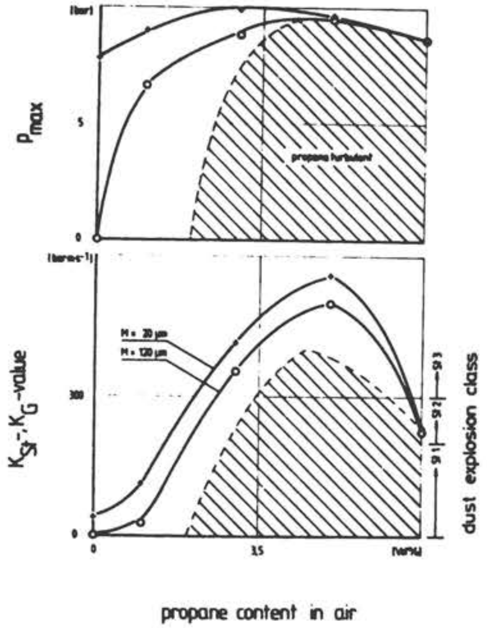


Fig. 21: Explosion data of dusts of pure PVC in presence of propane

Fig. 22 illustrates the influence of admixture of flammable gas or vapour on the minimum ignition energy of dusts. It appears that

d) low energy sparks that would not be capable to ignite a given dust dispersion may cause ignition of a "hybrid mixture" of that dust, even when the concentration of the gas or vapour component is below its lower explosion limit.

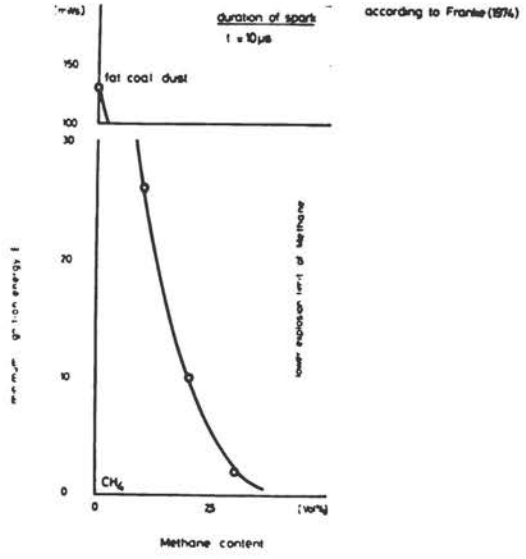


Fig. 22: Influence of methane content on the minimum ignition energy of fat coal dust

At present, CIBA-GEIGY carries out systematic research to establish the physical/chemical laws and interrelationships that govern the explosion behaviour of hybrid mixtures.

2.2 Explosion within Pipelines

Knowledge gained on data that characterise the course of explosions in pipelines is based on a large number of tests with flammable gases and combustible dusts of varying explosion violence (fig. 23 - 25). It was found that the course of explosions in pipelines is governed by the effects of flow and of changes in the state of turbulence in the unburnt explosive mixture ahead of the flame front. The normal burning velocity is of secondary importance. Explosion velocity and explosion pressure are the decisive phenomena.

Fig. 23: Pipelines for basic research
Ø 100 to 400 mm
length 40 m

Fig. 24: Pipeline for basic research
Ø 2500 mm
length 140 m

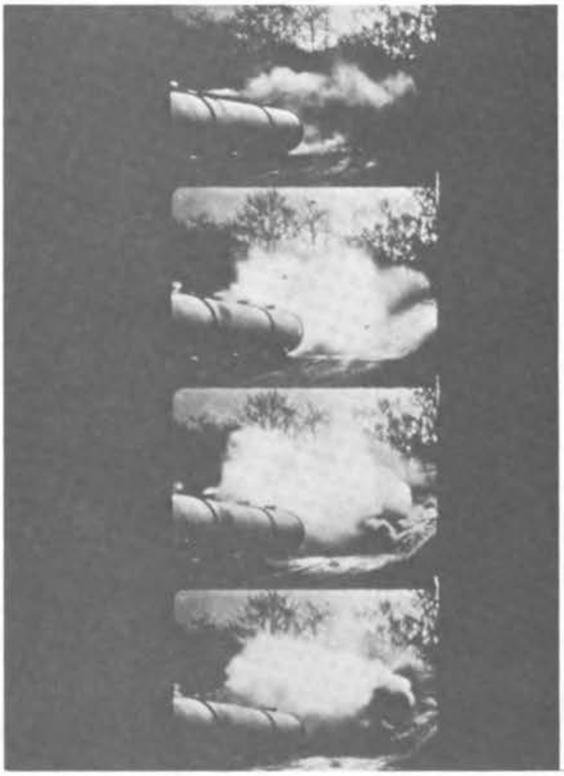


Fig. 25: Pipeline Ø 2500 mm
Fireball at end of
line during explosion
of 400 m^3 methane/
air-mixture

If a pipeline that contains an explosive mixture is open at one end and ignition is initiated at the closed end, then only approx. 1/8 to 1/7 of the mixture will burn within the line. The main quantity is expelled unburnt and will be ignited in the open air by the flame front advancing through the line (fig. 26).

Fig. 26: Pipeline Ø 1600 mm, length 10 m
Explosion of a pharmaceutical product
(dust, K_{St} = 200 bar·m·s^{-1})

Explosions of flowing, i.e. turbulent gas/air-mixtures and dust dispersions in pipelines - especially narrow ones - can change into detonations or "quasi-detonations" (fig. 27 and 28), with velocities of several km/s. The length of pipeline permitting acceleration to such very high velocities is in the order of 10 to 20 m for gases and of 20 to 40 m for dusts (polyethylene, wood, organic pigment).

For dusts - as well as for gases - the explosion pressure in pipelines shows a quasi linear relation to the explosion velocity and is practically independent of the nature of the dust (fig. 29). During an explosion (V_{ex} <500 m/s), the pressure in a pipeline will not exceed 10 bar; in case of a detonation (V_{ex} >500 m/s) however, a pressure in the range of 25 to 30 bar may act on the wall of the pipeline, i.e. perpendicularly to the direction of reaction propagation.

Comprehensive investigations have shown that pipelines designed for a nominal pressure of 10 bar will nevertheless withstand the very short pressure peaks caused by detonations, without bursting.

The same cannot be said of elevator casings made of thin sheet metal and having a rectangular cross section. Some test explosions with fodder and grain dusts (P_{max} = 7,5 - 9 bar, K_{St} = 70 - 150 bar·m·s^{-1}) were carried out in a small elevator leg, made of 2 mm steel, with a cross section of 230 x 270 mm. An explosion velocity of 250 m/s with pressures of 1,5 bar caused the casing to crack at the edges (fig. 30). Explosion velocities of 1000 m/s and pressures of 5 bar led to destruction (fig. 31/32).

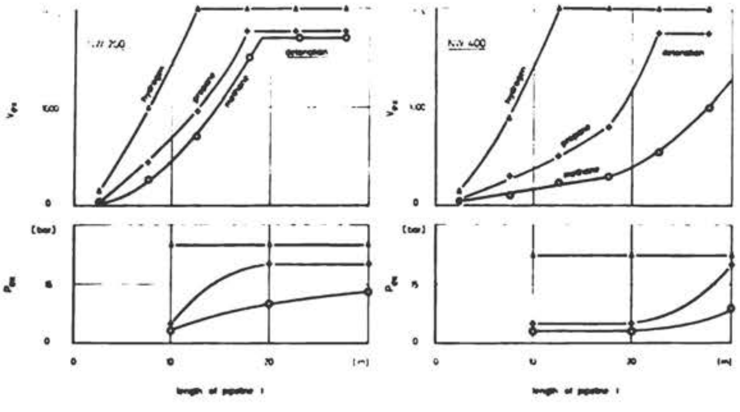


Fig. 27: The course of combustion of flowing gas/air-mixtures in pipelines

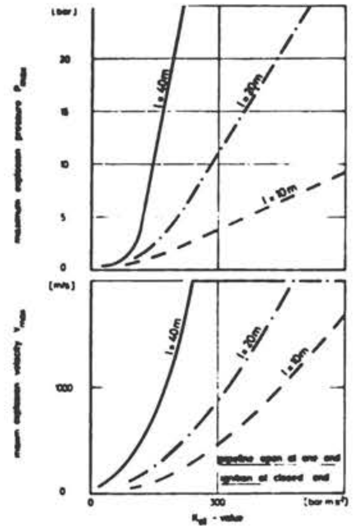


Fig. 28: The course of combustion of flowing dust/air-mixtures in pipelines

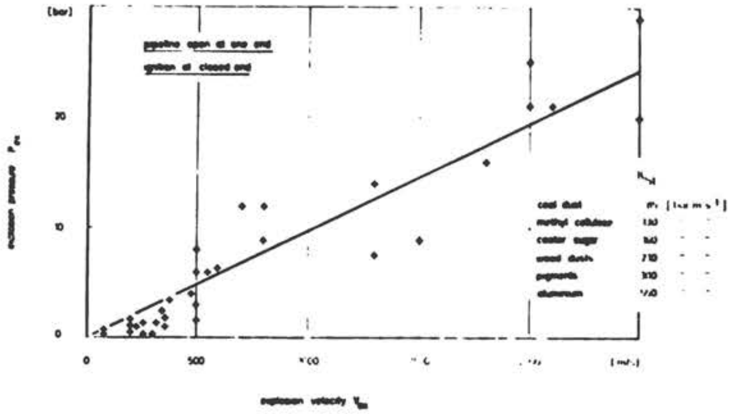


Fig. 29: Explosion pressure of dusts in pipelines
Ø 400 mm, length 40 m

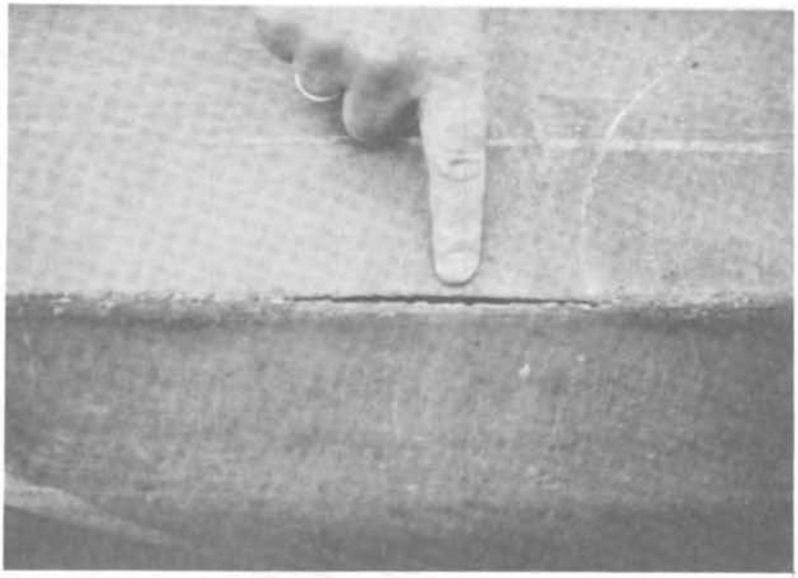


Fig. 30: Elevator leg, length = 24 m, after dust explosion

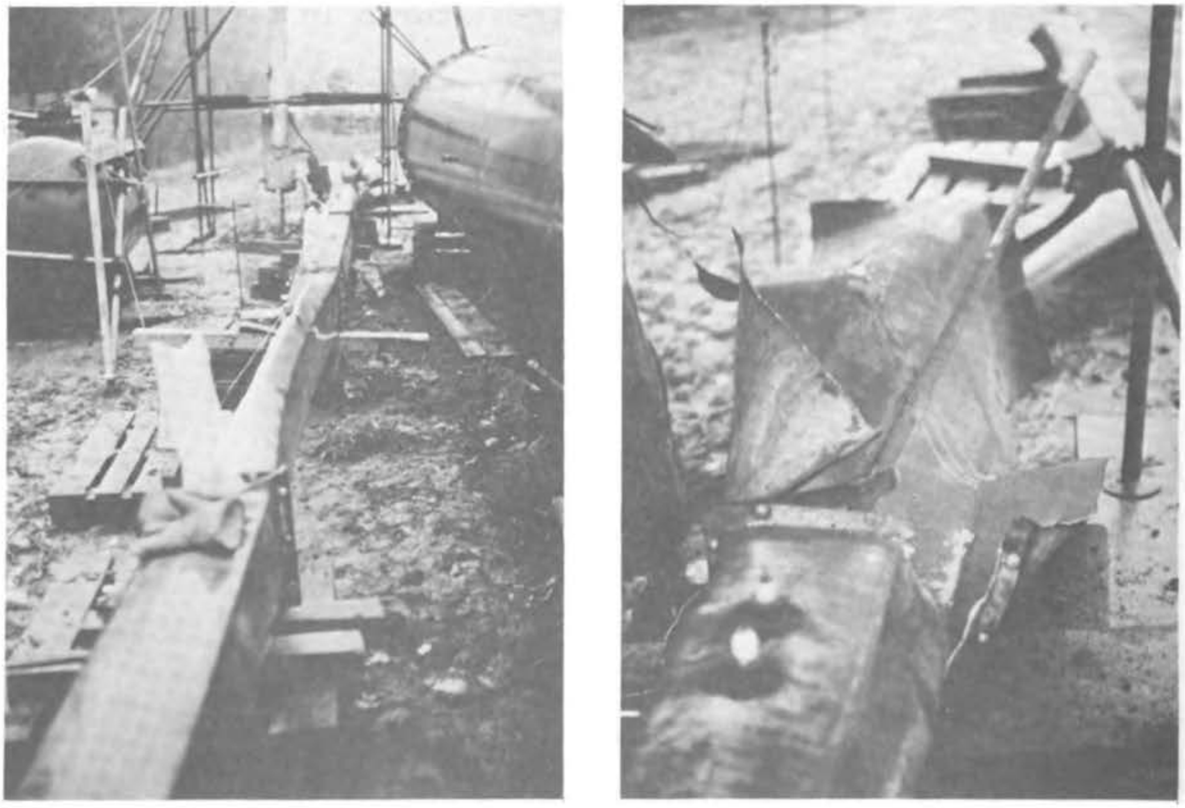


Fig. 31: Elevator leg, length = 24 m, after detonation of a dust/ air-mixture

3. PREVENTIVE MEASURES

3.1 Inertisation

If the oxygen content of the air is sufficiently reduced by admixture of a gas not supporting combustion, explosions can be prevented. This procedure is called inertisation. It is not necessary to eliminate oxygen completely. The maximum allowable oxygen content depends on the nature of the combustible material and must be determined experimentally for each case.

Inertisation of flammable gas/air-mixtures can be achieved e.g. by admixture of
- nitrogen
- carbon dioxide
- halogenated hydrocarbons.

Fig. 32 illustrates on the example of propane how the maximum values of the explosion data (P_{max}, $(dp/dt)_{max}$) are reduced with increasing inert gas content of the air available for combustion, depending on the nature of the inert gas (inhibitor).

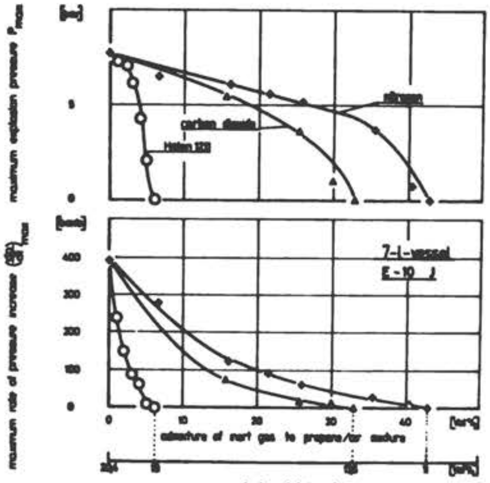


Fig. 32: Influence of different inhibitors on the explosion data of propane
7 l explosion chamber, E ≈ 10 J

The effectiveness of the inhibitors increases in this order:
Nitrogen → carbon dioxide → halogenated hydrocarbons.
Accordingly, for effective inhibition of propane explosions, the maximum allowable oxygen concentration in the air available for combustion is 11% vol for halogenated hydrocarbons.

It was found that when nitrogen or carbon dioxide is used as inert gas, flammable gas/air-mixtures with concentrations near the lower explosion limit require the highest proportion of inert gas for complete inertisation, whereas for halogenated hydrocarbons this is the case with stoichiometric mixtures. This can be explained by the fact that nitrogen and carbon dioxide have a "suffocating" effect while halogenated hydrocarbons actively interact with the mechanism of the combustion reaction (anticatalytic effect).

Certain extinguishing powders have a much higher inertising effect on combustible gas/air-mixtures than inert gases. Fig. 33 shows that rather small quantities of ammonium phosphate powder can be sufficient for inertisation. But the powder must be distributed evenly throughout the enclosure that is to be protected.

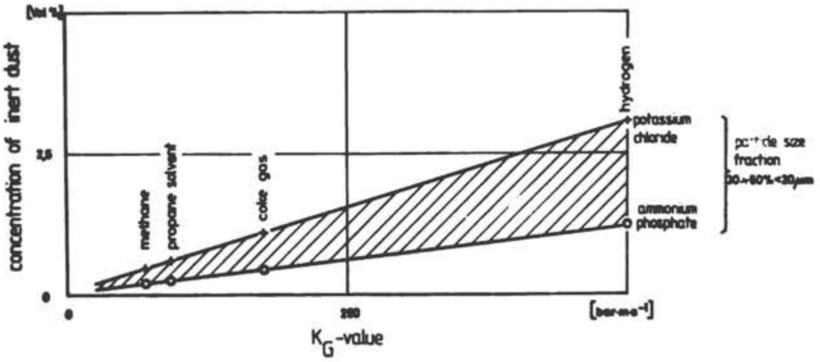


Fig. 33: Inertisation of flammable gases by means of extinguishing powders

Nitrogen is most frequently used to inertise dispersions of combustible dust. Fig. 34 illustrates that, with decreasing oxygen concentration, the explosive range of polyethylene dust is narrowed down more and more. Again, mixtures in the concentration range near the lower explosion limit need the highest proportion of nitrogen for complete inertisation.

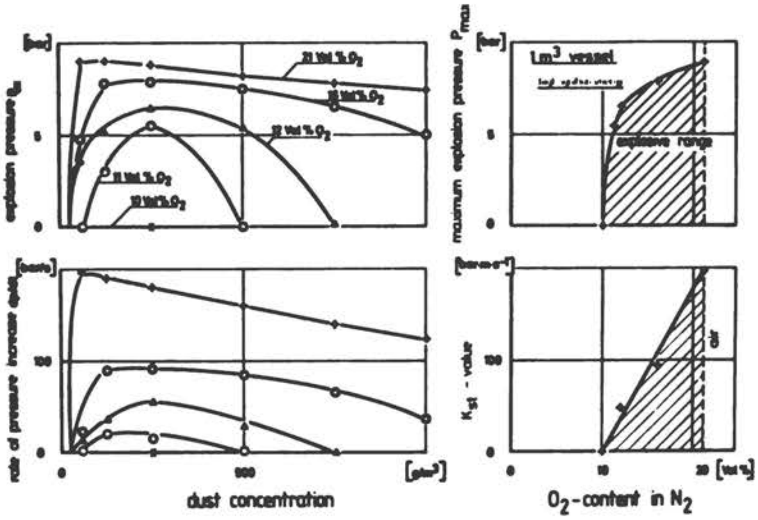


Fig. 34: Inertisation of polyethylene dust (M = 25 µm) with nitrogen

In general, dusts of organic material are no longer explosive if the oxygen concentration is below 10% vol, but certain exceptions are known, i.e. 2-naphtol, bisphenol A and paraformaldehyde.

With regard to the application of halogenated hydrocarbons for the inertisation of combustible dust/air-mixtures, it must be noted that the minimum inert gas concentration required depends largely on the nature of the combustible dust; it varies from 10% vol for coal dust to 70% vol for dextrine to 90% vol for aluminium dust.

If extinguishing powders are used for inertisation, this is mostly done by mixing them thoroughly with the combustible dust. The extinguishing effectiveness depends mainly on the nature of the powder used, but often, more than 50% wt will have to be added. It was found that extinguishing powders on the basis of ammonium phosphate are most effective to prevent dust explosions. In special cases, powders on the basis of sodium or potassium bicarbonate can also be used.

4. PROTECTIVE MEASURES AGAINST THE EFFECTS OF EXPLOSIONS

4.1 Preliminary remarks

While the preventive measure "inertisation", if applied correctly, will prevent the occurrence of gas and dust explosions altogether, the measures described hereafter will only reduce the hazardous effects of explosions. Such measures should always be taken if explosive mixtures may be present in an industrial plant where inertisation is not feasible and ignition sources cannot be excluded with certainty.

4.2 Pressure resistant design

An apparatus can be designed to withstand the full maximum explosion pressure generated by an exploding fuel/air-mixture, without being ruptured or undergoing deformation. In most countries, this would have to be done according to the design codes for pressure vessels being locally in force. Such design usually ensures a comfortable safety margin for the mechanical strength of the vessel. - In the recent past, "pressure shock resistant" design has become more and more popular (fig. 35). Pressure shock resistant vessels have less mechanical strength. They can still withstand the full maximum explosion pressure, but it is accepted that, in case of an internal explosion, permanent deformation (without rupture) may occur and extensive repairs or replacement may become necessary.

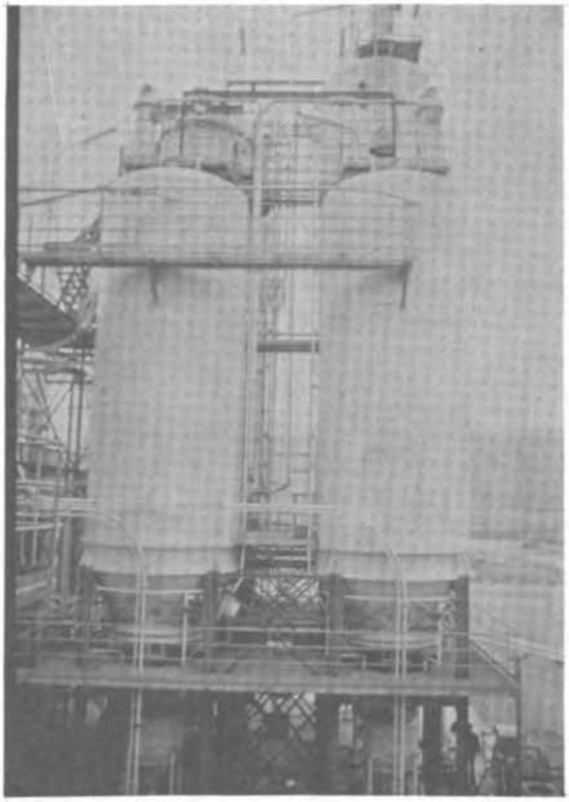


Fig. 35: Vessel of a production plant; explosion pressure shock resistant design

4.3 Explosion Pressure Relief

4.31 Vessels

The protective measure "explosion pressure relief" aims to prevent the buildup of an unacceptably high internal pressure by the timely opening of a relief area. But the vessel to be protected must still be designed to withstand a certain reduced explosion pressure (pressure resistant or pressure shock resistant).

A large number of explosion relief tests involving a great variety of fuels in enclosures from 1 m^3 to 60 m^3 under controlled, constant conditions have shown that the "Cubic Law" explained earlier in this paper is not only valid for closed vessels but also for "pressure relieved" vessels. Thus, nomograms could be worked out (fig. 41) that allow to read the size of the relief area for any volume of an apparatus as a function of the explosion data of the combustible material and the mechanical strength of the apparatus to be protected.

Practical tests on a 1:1 scale included test explosions in pocket filters (fig. 42) and dust separators (fig. 43) with internal fittings. Thereby it was found that for sizing the relief area, the free volume of the apparatus (i.e. total volume minus volume of internal fittings such as filter pockets, filter bags) can be taken as a base. This is due to the fact that the suface of the internal fittings will absorb a certain part of the energy set free by the explosion, resulting in a lower explosion pressure. But the internal fittings must not obstruct free flow through the relief opening.

However, if an explosion propagates through a pipeline into a filter apparatus - and this is usually the case in industrial operations (fig. 44/45), the relief areas for the full volume (as indicated by the diagram fig. 41) must be applied and successful relief will only be possible if the flame jet from the pipeline enters the filter apparatus at comparatively low velocity (some m/s).

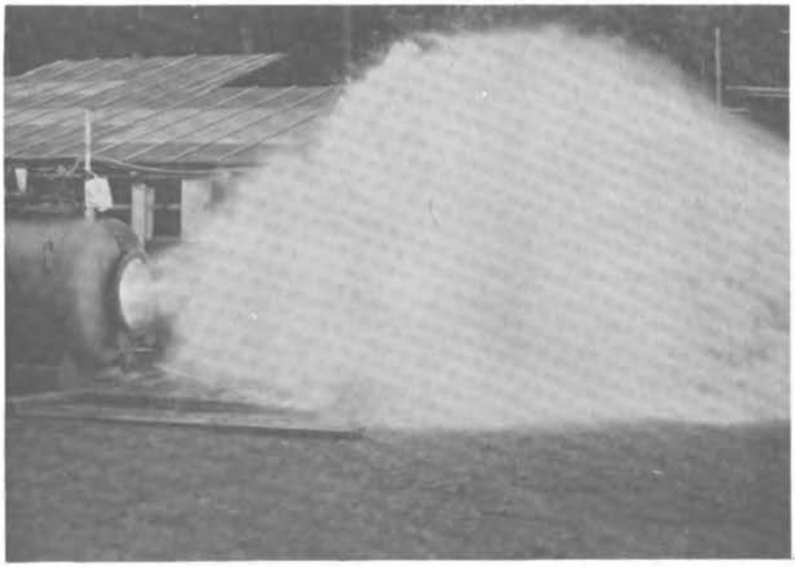


Fig. 36: 2 m^3 vessel with pressure relief.
Cellulose dust explosion

Fig. 37: 10 m^3 vessel with pressure relief. Pigment dust explosion

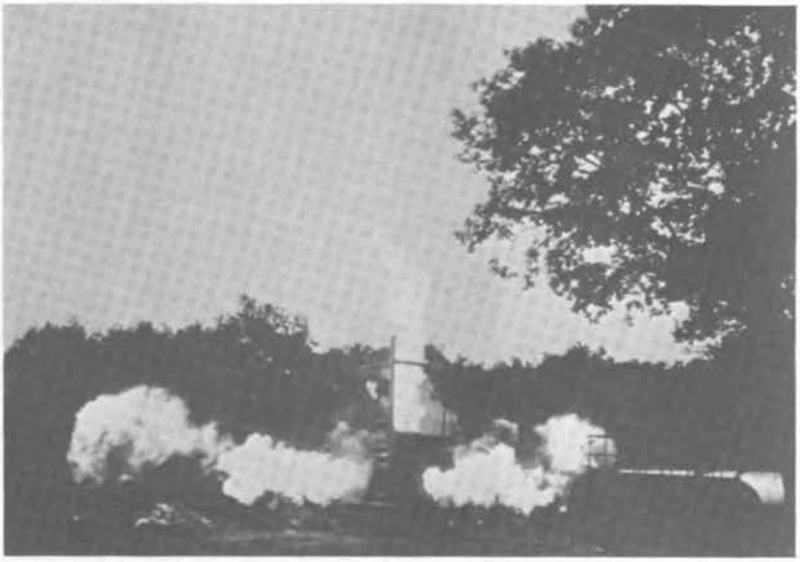


Fig. 38: 30 m^3 vessel with pressure relief. Pigment dust explosion

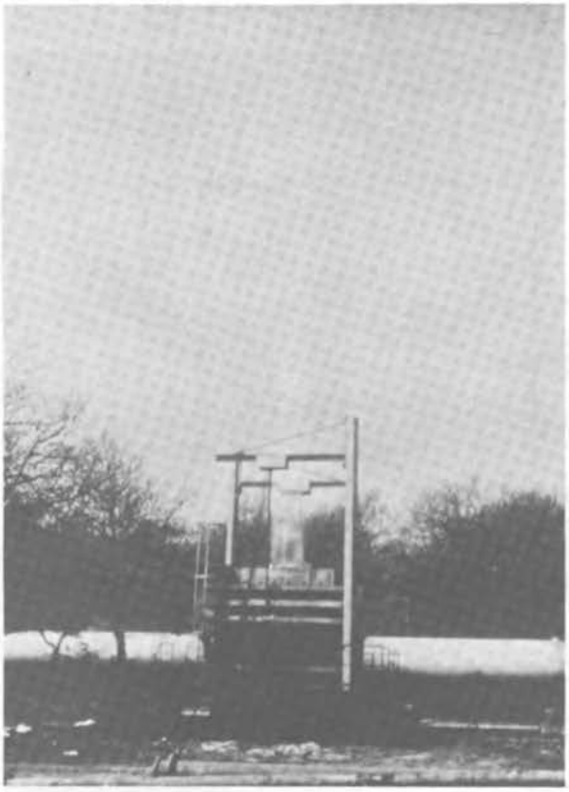


Fig. 39: 30 m^3 vessel with pressure relief. Propane gas explosion

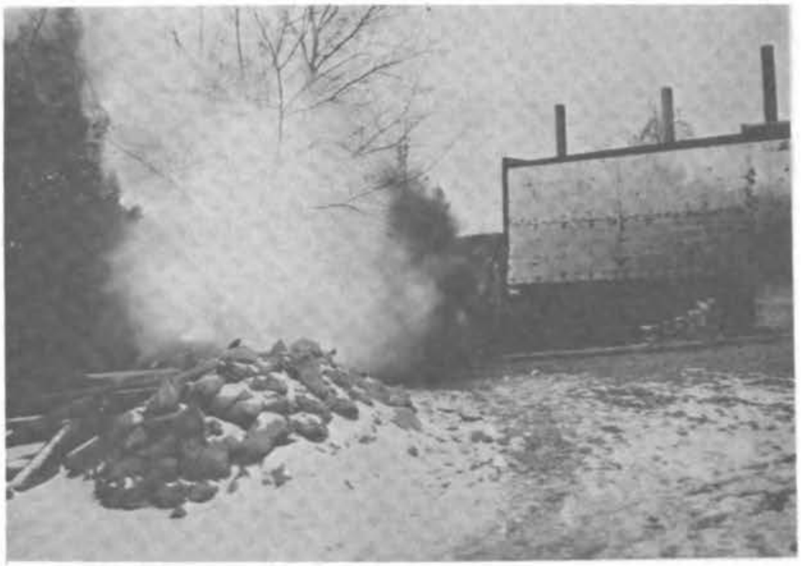


Fig. 40: 60 m^3 bunker with pressure relief.
Coal dust explosion

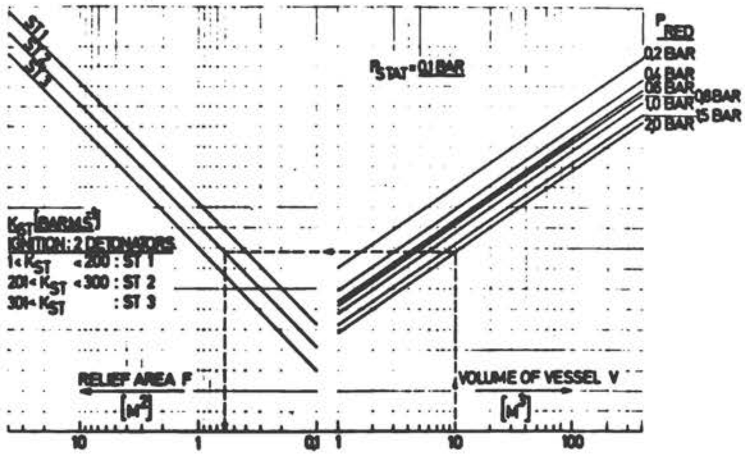


Fig. 41: Example of nomogram for sizing relief areas for combustible dusts

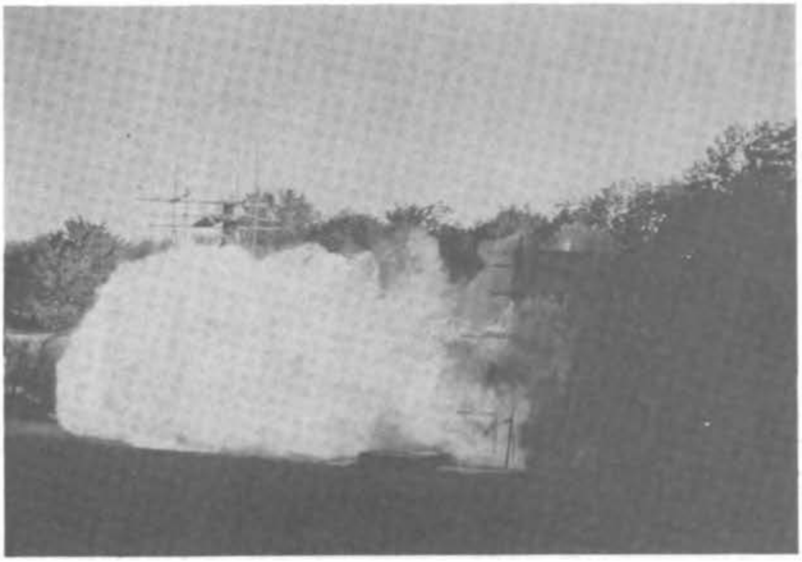


Fig. 42: Dust explosion in pocket filter
$V = 8\ m^3$, $K_{St} = 300\ bar \cdot m \cdot s^{-1}$

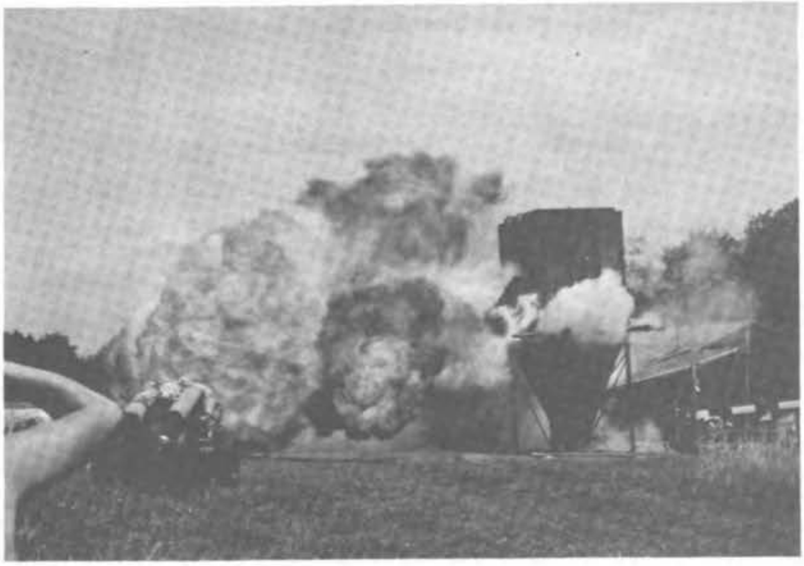
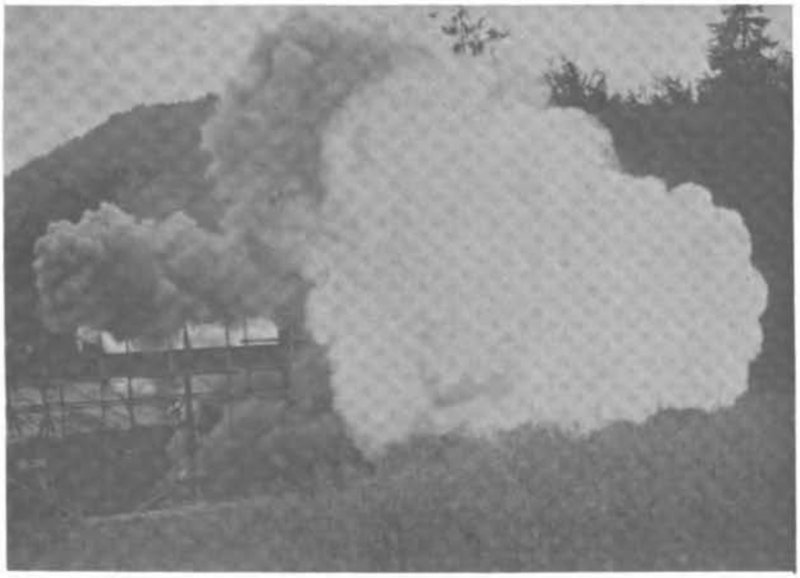
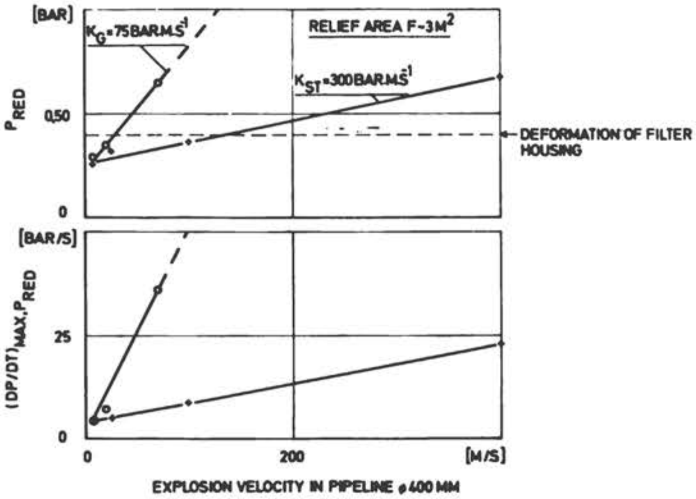


Fig. 43: Dust explosion in bag filter
$V = 14\ m^3$, $K_{St} = 300\ bar \cdot m \cdot s^{-1}$



<u>Fig. 44</u>: Bag filter. Pigment dust explosion ignited by slow flame jet from pipeline. K_{St} = 300 bar·m·s^{-1}



<u>Fig. 45</u>: Explosion data measured in bag filter enclosure. Flame jet ignition

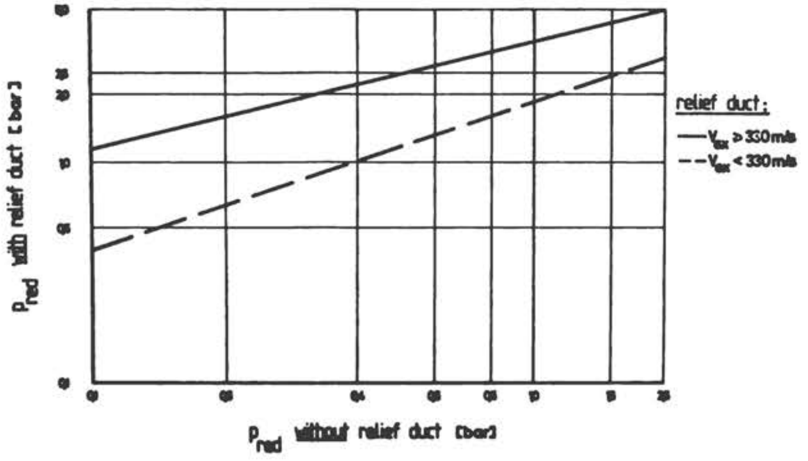


Fig. 46: Combustible dusts: Influence of relief duct on reduced explosion pressure P_{red}

In the case of high flame velocity (some 10 m/s), this velocity must either be reduced by constructive measures at the point where the pipeline joins the filter enclosure, or entrance of the flame must be prevented altogether by a suitable barrier device (see section 4.2). Otherwise, the filter enclosure will be destroyed unless it is of very high mechanical strength.

If apparatus with explosion pressure relief are installed within buildings, it will be necessary to fit the relief opening with a relief line or duct to the open, in order to protect personnel and working rooms from flames, combustion gases, pressure wave etc. in case of activation of the relief device. Thereby it must be kept in mind that the flow resistance created by such a relief duct or line will lead to a considerable increase of the reduced explosion pressure (fig. 46).

Although the cubic law and the design formula for explosion pressure relief have been confirmed experimentally by test explosions so far in a volume range from 1 to 60 m^3 only, there is ample evidence that they are appliccable also for much larger volumes, e.g. 1000 m^3.

4.31 Vessels of Elongated Shape (Silos)

The nomograms for relief areas described in section 4.31 are not appliccable to vessels of elongated shape (e.g. silos),

i.e. vessels with a ratio $\frac{\text{height (H) or length (L)}}{\text{Diameter (H)}} > 5:1$.

In such elongated vessels, an explosion will create a strong axial flow, and as a consequence the course of an explosion will be more similar to explosions in pipelines than to explosions in vessels of spherical or cubic shape. Therefore, on elongated vessels (silos), the entire cross section area will have to be used as a relief area (blowoff-top). If relief areas are installed on the side, the whole top cover may still be blown off by an explosion (fig. 47).

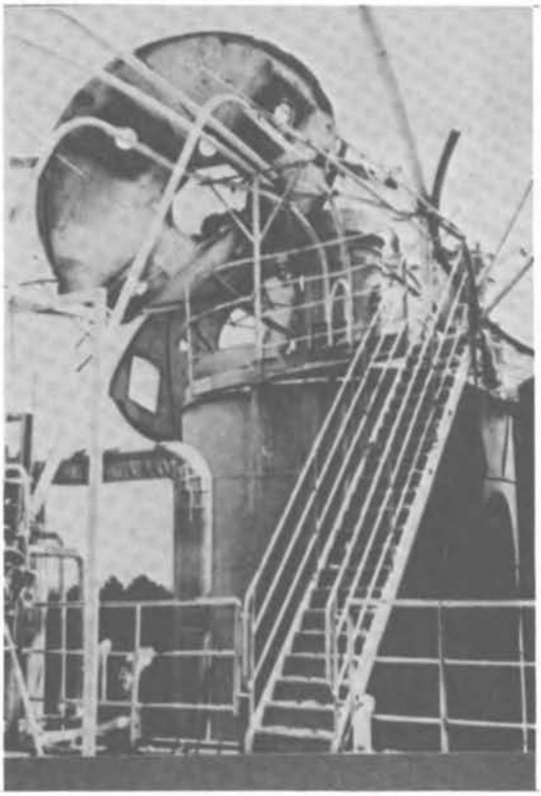


Fig. 47: Blown off cover after dust explosion in a vessel with partial relief

For sizing relief areas on elongated vessels (silos), the following limitations have to be kept in mind:

a) Although the whole cross section will be used for explosion relief, the size of the relief area must not be smaller than the area to be read from the nomogram (fig. 41) as a function of volume. This leads to a maximum volume that can be relieved effectively.

b) The nomogram should not be applied to volumes larger than 1000 m^3.

This limitation leads to a certain interdependence between the diameter, the maximum allowable height and the mechanical strength of a silo; this strength has a decisive influence.

Since the whole cross section or roof area F_2 is the maximum relief area that can be accommodated on a silo (relief on the side being not effective), the maximum volume V_2 that can be protected can be calculated, using the cubic law, as follows

$$V_2 = \sqrt{\left(\frac{F_2}{F_1}\right)^3} \cdot V_1$$

F_1 is the relief area required to protect a volume of $V_1 = 1\ m^3$ with the same pressure resistance of the enclosure as the larger apparatus (V_2) to be protected. This area can be read from nomograms. For both volumes V_1 and V_2, the reduced explosion pressure and the static activation pressure of the relief area will then be the same.

The limitations of the height of a silo that has to be protected against dust explosions by pressure relief, as the result of this interrelationship, is shown for silo diameters of D = 4 m and D = 8 m in fig. 48.

Fig. 49 shows the influence of the diameter of a silo on the maximum allowable height, for a given mechanical strength, i.e. maximum allowable internal pressure P_p = reduced explosion pressure P_{red} = 0,4 bar, for different dust explosion classes.

Similar considerations will have to be made if a silo will be protected by pressure relief against explosions of flammable gases or solvent vapours.

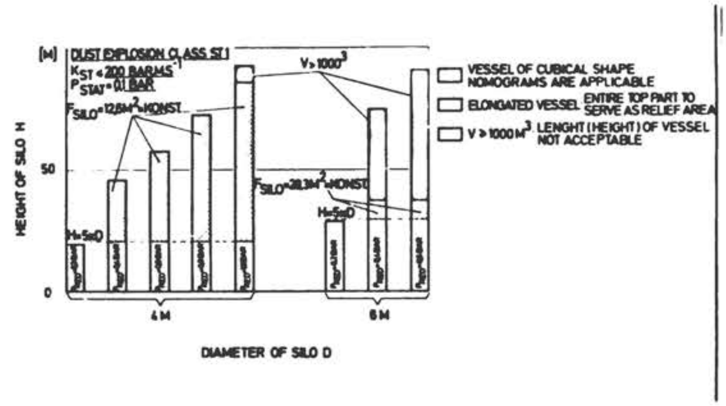


Fig. 48: Influence of the pressure resistance on the maximum allowable height of a silo, as derived from nomograms

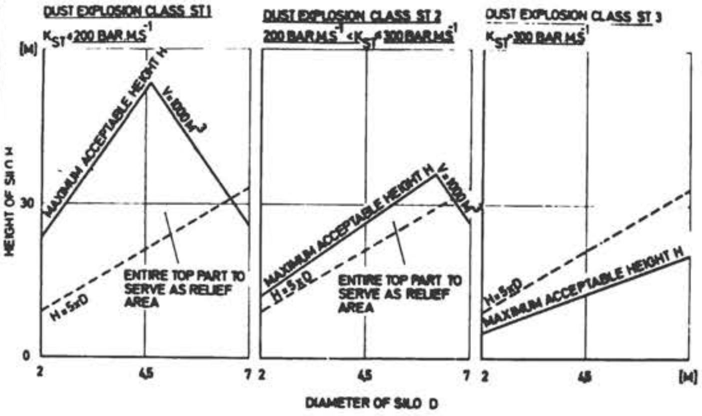


Fig. 49: Influence of the dust explosion hazard class on the maximum allowable height of a silo for

P_{stat} = 0,1 bar, P_{red} = 0,4 bar

P_{stat} = static activation pressure of the relief device

P_{red} = reduced explosion pressure = maximum allowable internal pressure

Fig. 50 shows a pressure relief device for an elongated vessel (silo) immediately prior to being explosion tested on the test site of CIBA-GEIGY Limited, near Basle. In case of a mild dust explosion, only the circular relief openings intended for partial relief will be opened (fig. 51). A violent dust explosion will blow open all the segments of the top, but no fragments will be blown away. Fig. 53 shows such a pressure relief device installed on a silo for which the possibility of a dust explosion connot be ruled out.

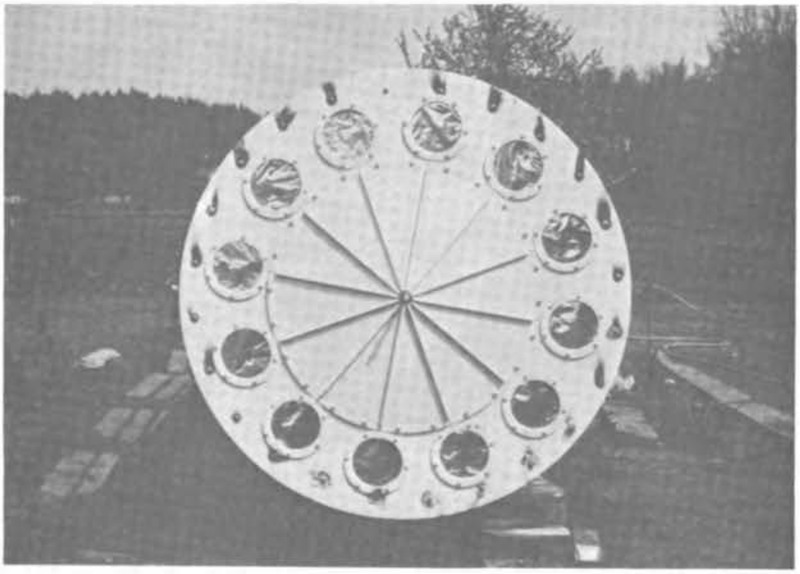


Fig. 50: Pressure relief device for a silo Ø 1600 mm
(Static activation pressure P_{stat} = 0,1 bar)

Fig. 51: Pressure relief device Ø 1600 mm as shown in fig. 50 after being activated by a dust explosion (dust explosion hazard class St 2)

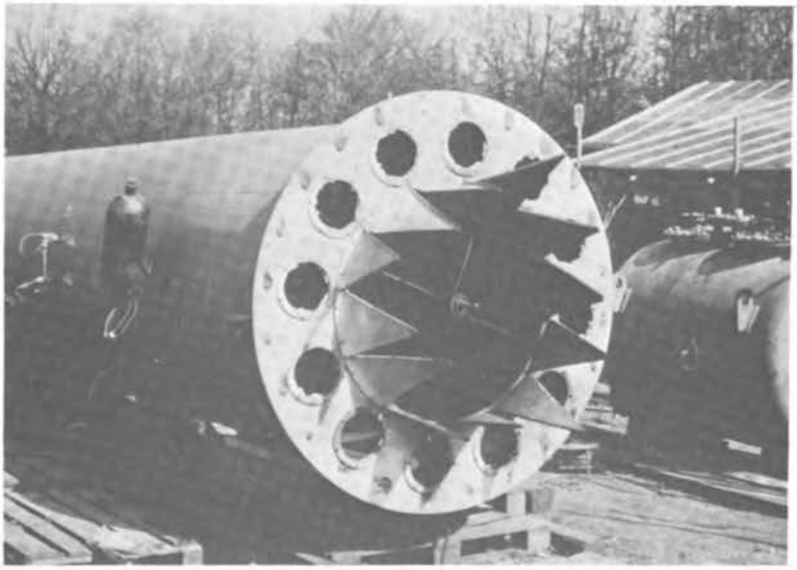


Fig. 52: Pressure relief device Ø 1600 mm after dust explosion

Fig. 53: Roof area of a silo designed for pressure relief

4.33 Pipelines

Effective explosion pressure relief of pipelines and ducts is only possible, if relief devices are installed over its whole length, at short distances (every 1 or 2 meters). Thereby, especially in the case of dust explosions, voluminous flames will emanate from each of the relief openings (fig. 55). Therefore, the application of this protective measure on pipelines and ducts is limited to open air installations.

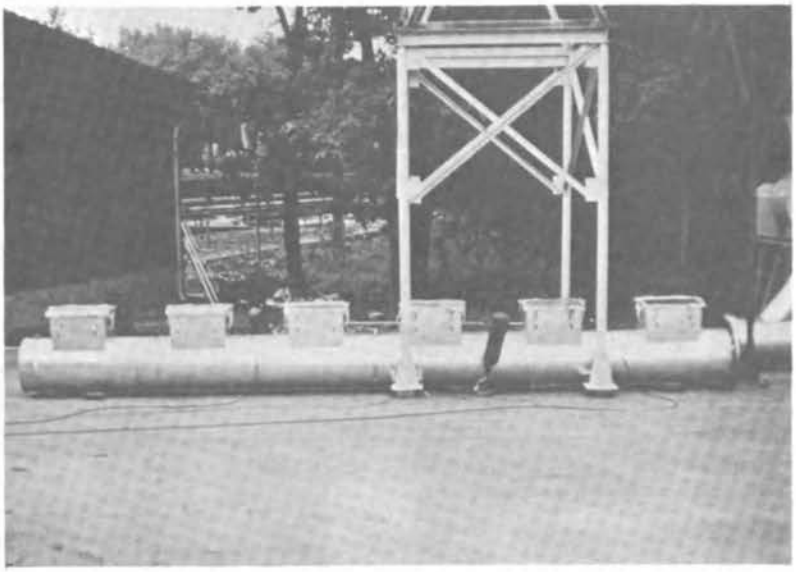


Fig. 54: Pipeline with pressure relief

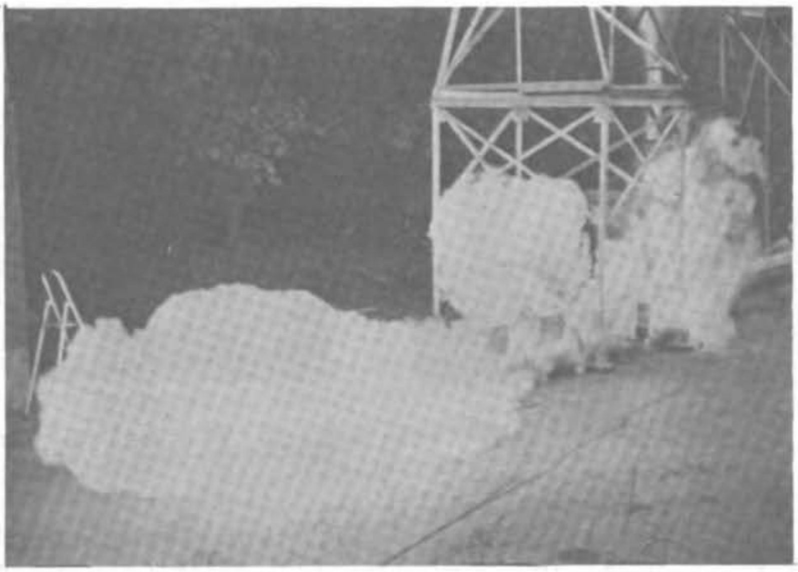


Fig. 55: Wood dust explosion in a relieved pipeline

Where explosion pressure relief is not practicable, pipelines and ducts within which explosions are to be expected must be designed for a nominal pressure of 10 bar (approved codes). Such lines and ducts will "survive" the extremely short peak pressure of a detonation. But on flanges to branch pipes and on bends, precompression and reflexions will lead to much higher peak pressures than those to be expected in the straight parts of the line. These critical parts have to be protected by approved relief devices, e.g. explosion doors or spring loaded valves (fig. 56 - 58).

It is emphasized that these relief devices will by no means reduce the pressure load in the pipe or duct system. Their activation will lead to higher explosion velocities and therefore to higher peak pressures. They can only serve to prevent destruction of critical parts.

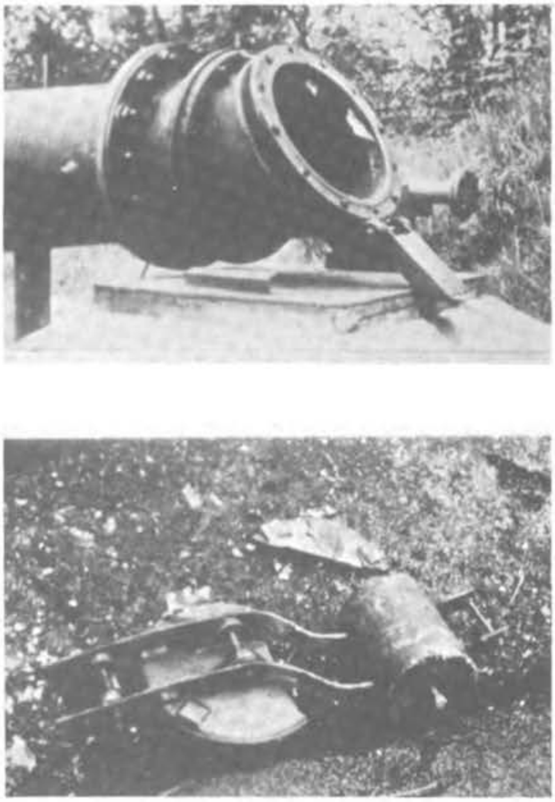


Fig. 56: Relief device at end of pipeline after explosion. Insufficient mechanical strength

Fig. 57: Relief device at end of pipeline Adequate mechanical strength

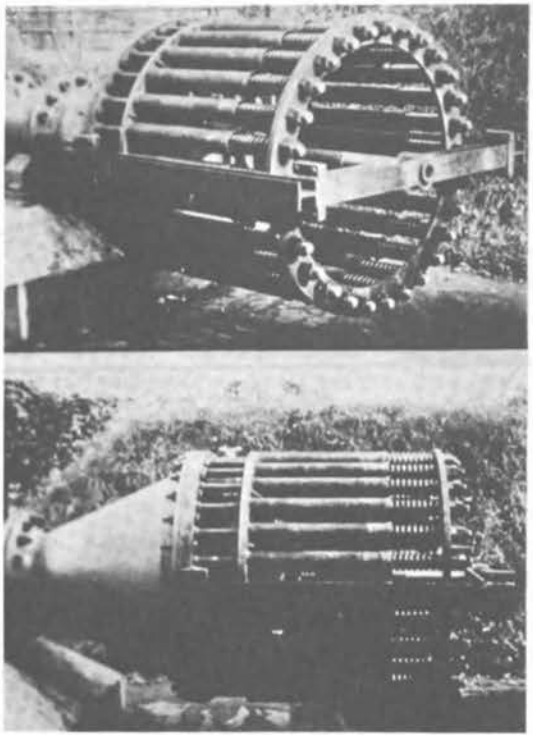


Fig. 58: Spring loaded relief device at end of pipeline

4.4 Explosion Suppression

With explosion pressure relief as described in section 4.3, the appearance of voluminous flames, combustion gases, unburned fuel/air-mixture and pressure waves in the vicinity of the relief area or of the relief duct is unavoidable. Explosion suppression will reduce all these effects and confine them to the interior of the apparatus. Sensitive pressure detectors "feel" an explosion in its very early stages and activate the valves of pressurised extinguishers. Within milliseconds, extinguishing medium is injected into the apparatus to be protected, thus quenching the explosion before it can fully develop. As a result, the explosion pressure is markedly reduced (fig. 59). The reliability of such suppression devices is very high.

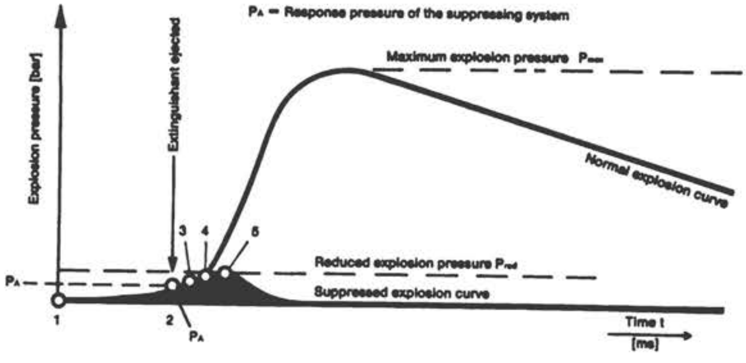


Fig. 59: Pressure vs time of a "normal" and of a suppressed dust explosion

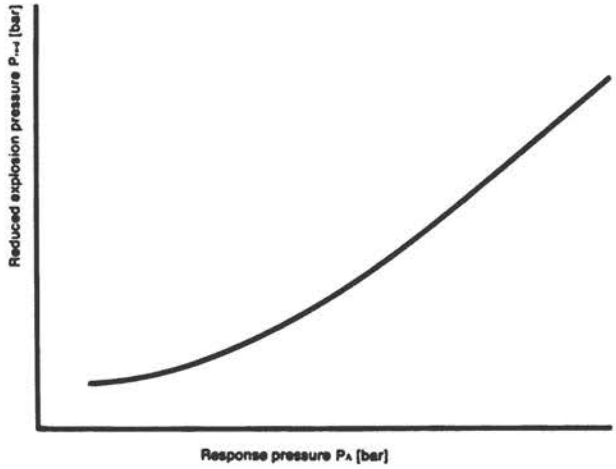


Fig. 60: Static activation pressure P_A of suppression system vs reduced explosion pressure P_{red}

As a matter of principle, the relationship between activation pressure P_A of the suppression system and the reduced explosion pressure P_{red} prevailing after the suppression process, as shown in fig. 60, can be observed for any given combustible gas, vapour or dust. If very effective extinguishing media are used, an increase of the activation pressure will cause only a moderate increase of the reduced explosion pressure. This is of importance for plant operations since extemely low activation pressures may lead to frequent nuisance alarms, caused e.g. by vibrations or "normal" pressure oscillations. This requirement is met by certain extinguishing powders, due to their outstanding inertising capacity (see section 3.1). Compared with halogenated hydrocarbons that are frequently used as explosion suppressants, the application of extinguishing powders in suppression systems has the advantage that gas and dust explosions can still be successfully suppressed at comparatively high activation pressures and thus nuisance activations are avoided almost completely. If suppression systems using Halons (halogenated hydrocarbons) are activated inadvertently too late, i.e. when the explosion to be quenched has already developed to a certain extent, there is the risk that the suppressing agent will amplify the violence of the explosion and a higher explosion pressure will be generated than without any suppression at all. Therefore, in the recent past, suppression systems have been developed (mainly in european countries) that use extinguishing powder on the basis of ammonim phosphate as a suppressant.

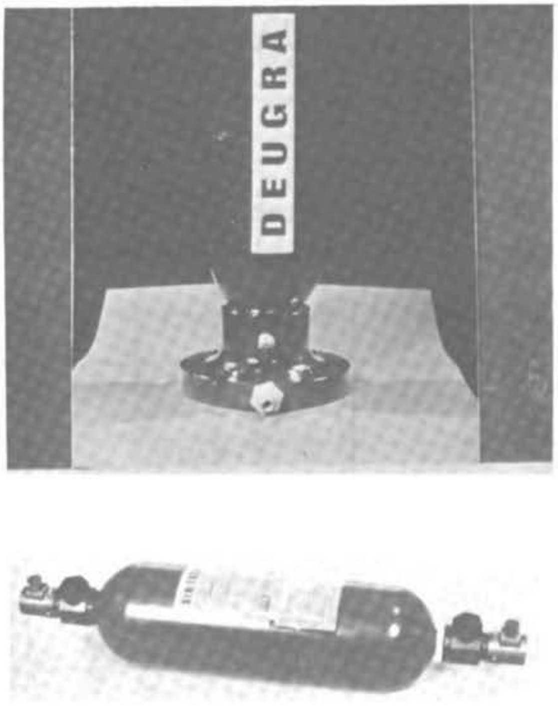


Fig. 61: Pressurised extinguisher for suppression system. Top: 3" system Bottom: $^3/_4$ " system

The extinguishing powder is stored in quantities of 4 kg in steel bottles (extinguishers) pressurised with nitrogen. There is a 3" system, with 60 bar nitrogen pressure and a 3" valve on the extinguisher activated by a cutting wire (fuse), and a ¾" system with 120 bar nitrogen pressure and a ¾" valve on the extinguisher, activated by a detonator. Both systems are almost equally effective. Dispersions of the extinguishing powder throughout the volume to be protected is achieved by special hemispherical nozzles. Fig. 62 shows that extinguishing powders on the same basis - e.g. ammonium phosphate - but from different suppliers can be very different in their extinguishing power. It is of utmost importance that only the most effective powder is selected for suppression purposes.

The quantity of suppressant, i.e. the number of extinguishers required for effective suppression of gas and dust explosion in closed vessels is not in proportion to the volume to be protected. Systematic investigations by means of suppression tests in volumes from 1 to 60 m^3 have revealed that the "cubic law" is also decisive for the quantity of suppressant required (fig. 63). This quantity can be calculated from Table 10 for various combustible materials.

Table 10: Minimum quantity of suppressant required, activation pressure P_A = 0,1 bar; best available powder

Combustible material	K_G, K_{St} (bar·m·s^{-1})	Number of 4 kg extinguishers	Minimum pressure resistance of enclosure to be protected (bar)
Methane at low or medium turbulence	200	$0{,}81 \cdot V^{2/3}$	1,0
Propane at low turbulence	200	$1{,}08 \cdot V^{2/3}$	1,0
Dust class St 1	$\leq$200	$1{,}08 \cdot V^{2/3}$	0,5
Dust class St 2	201 - 300	$1{,}4 \cdot V^{2/3}$	1,0

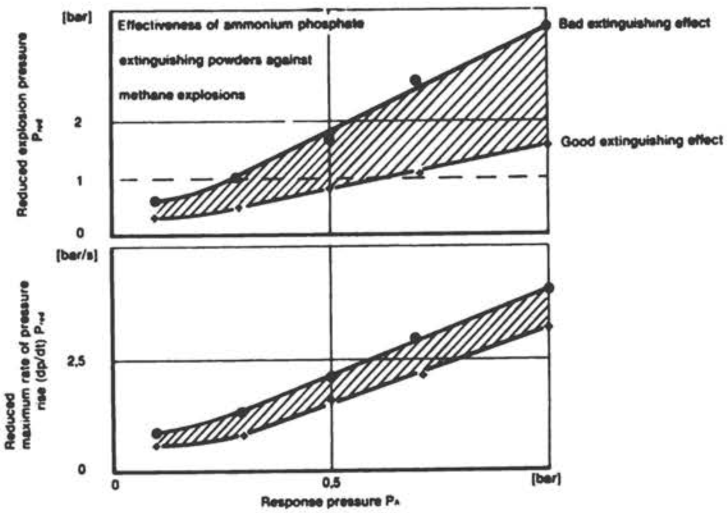


Fig. 62: Quality of suppressant powder vs suppression effectiveness

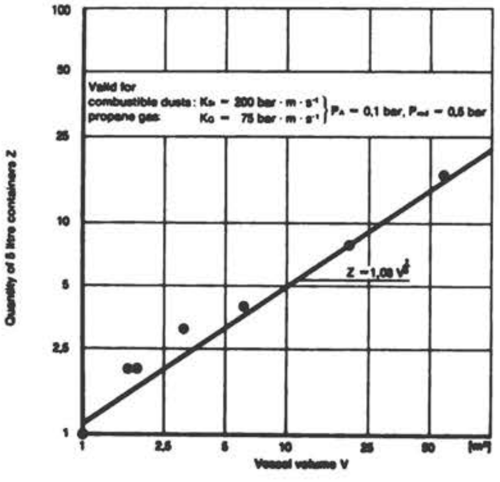


Fig. 63: Quantity of suppressant powder required to suppress gas and dust explosions in vessels of different sizes

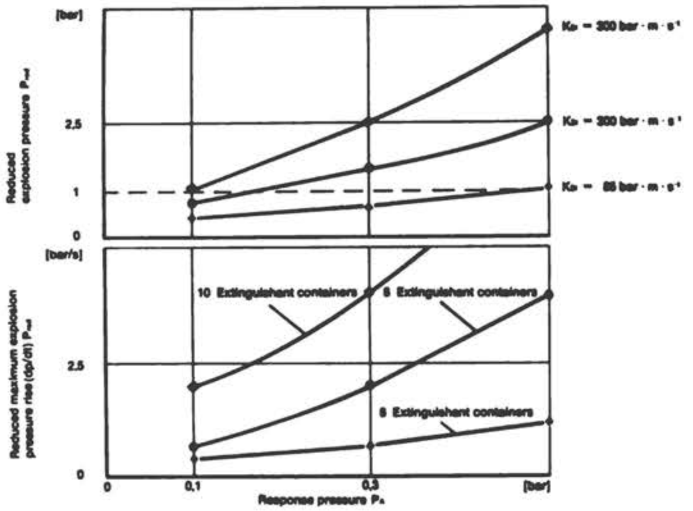


Fig. 64: Explosion suppression in a 20 m^3 vessel, with dusts of different explosion violence

Interpretation of the test results summarised in table 10 and fig. 64 leads to the conclusion that there are certain limitations to the application of explosion suppression systems, mainly due to the limited dispersion velocity of the extinguishing powder. These limitations can be characterised as follows:

flammable gases $K_{G\ max}$	200 $bar \cdot m \cdot s^{-1}$
combustible dusts $K_{St\ max}$	300 $bar \cdot m \cdot s^{-1}$
throwing range of suppressant (distance from periphery to center of vessel to be protected)	approx. 10 m

Beyond these limits effective suppression is not possible in industrial plant. Thus, hydrogen explosions ($K_G = 550\ bar \cdot m \cdot s^{-1}$) and aluminium dust explosions ($K_{St} = 500\ bar \cdot m \cdot s^{-1}$) cannot be suppressed. At best, a certain reduction of the explosive range can be achieved.

Fig. 65: $^3/_4$ " suppression system on the cone of a spray dryer

4.5 Explosion Barrier Devices

Often, mechanical flame arresters with corrugated metal ribbons are used to stop the propagation of gas explosions through pipelines. By the corrugated ribbon, the cross section of the pipeline is subdivided into a great number of narrow channels with small cross sections through which flames cannot pass. There are three types of these devices:

a) explosion arresters

b) flame arresters

c) detonation arresters

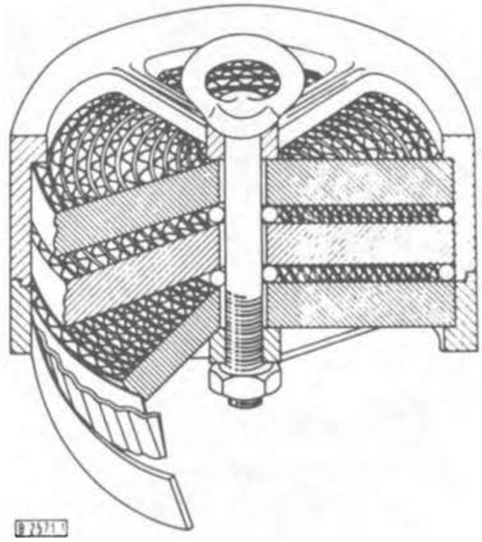


Fig. 66: The interior of a 3-stage flame arrester using corrugated ribbons

To prevent the propagation of dust explosions through pipelines, the automatic suppression barrier was developed (fig. 67). A suitable optical sensor will detect the approaching flame front and trigger the valve of a pressurised extin-

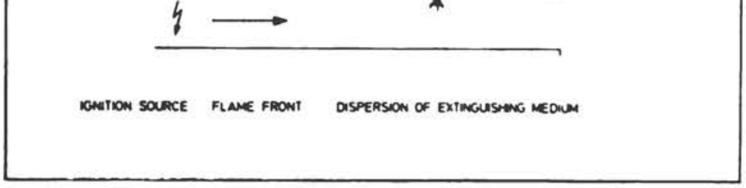


Fig. 67: Automatic suppression barrier (schematic)

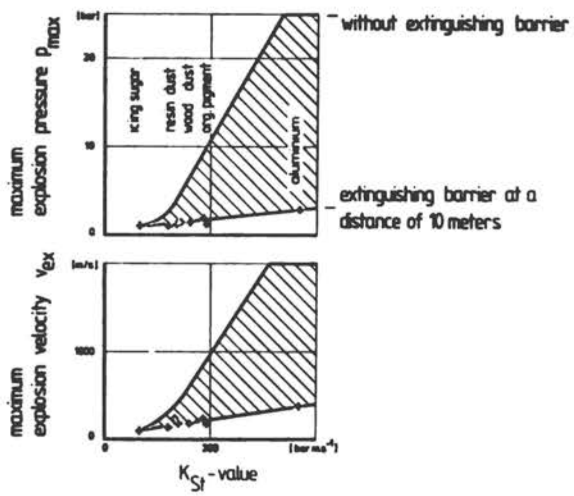


Fig. 68: Effectiveness of suppression barrier against dust explosions (pipeline diameter 400 mm)

guisher. The extinguishing medium - preferably extinguishing powder on the basis of ammonium phosphate - will be dispersed through special nozzles, thereby quenching the flame front as it passes. The quantity of suppressant (number of extinguishers) required depends on the cross section of the pipeline and on the expected explosion velocity.

In fig. 68, the explosion data of combustible dusts in a pipeline Ø 400 mm are compared with data measured after a suppression barrier at a distance of 10 m from the origin of ignition had been activated. This system is capable not only to confine the flames of an explosion to a predetermined part of the pipeline, but also to prevent the occurrence of violent explosions or even detonations in pipelines.

The application of automatic suppression barriers is by no means limited to pipelines with small cross sections, it can also effectively quench dust or even gas explosions in large pipelines (or elevator legs), as is shown in fig. 69 and 70.

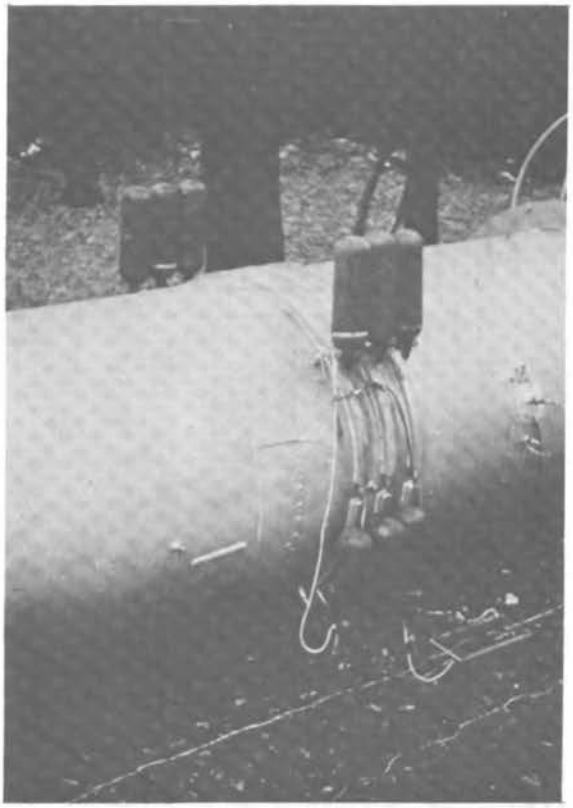
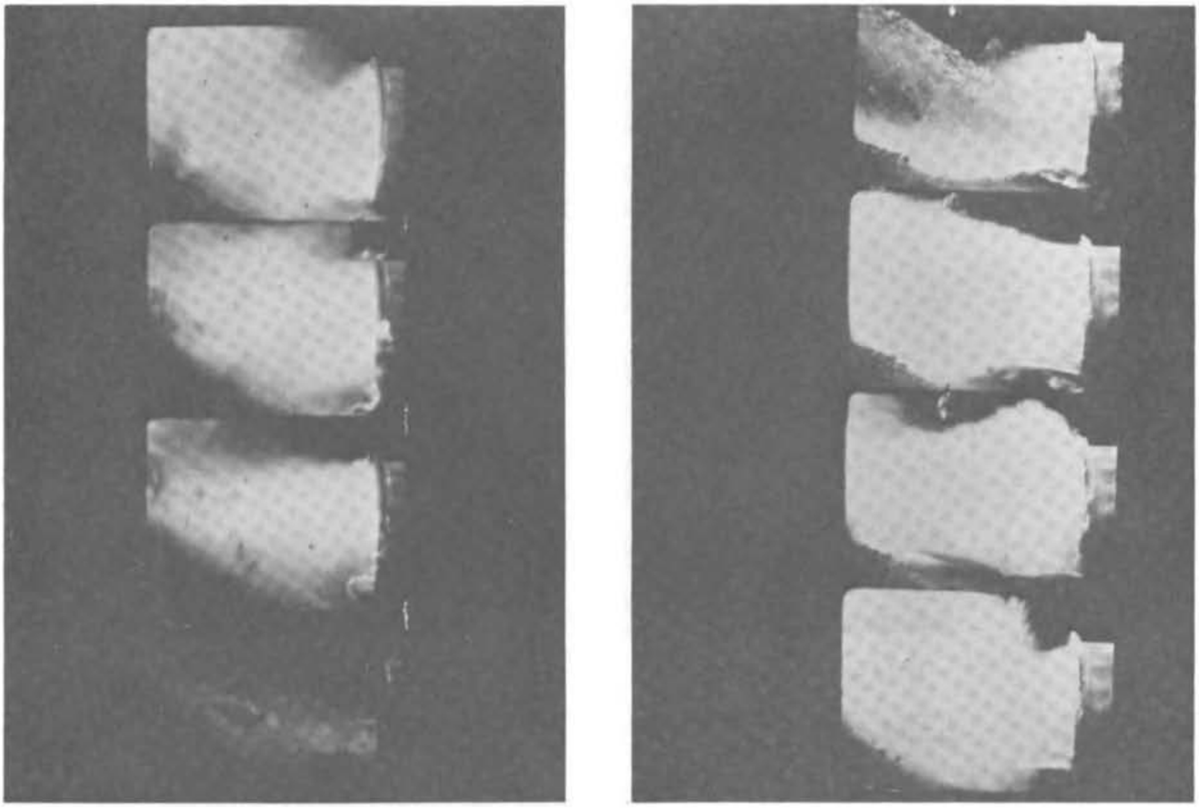


Fig. 69: Automatic suppression barrier for pipeline Ø 1400 mm



without suppression barrier with suppression barrier

Fig. 70: Pipeline Ø 1400 mm, l = 40 m
Methane explosion

There are situations where it is preferable to block off a pipeline hermetically in case of an explosion, e.g. to prevent propagation of a dust explosion from one container into an other one, by means of a rapid action valve. The valve shown in fig. 71 has performed very well in many applications. It does not need any electrical controls, it is activated by the pressure wave of the explosion itself that is preceding the flame front.

In case of need - e.g. if only extemely mild explosions are expected that would not create sufficient pressure to close the valve - the valve can also be power activated by a burst of compressed air or nitrogen from a pressurised container. But then, of course, an optical sensor will have to be installed at some point "upstream" (with regard to the direction of the explosion); sensors are also needed for the compressed air driven rapid action valves shown in fig. 72 and 73.

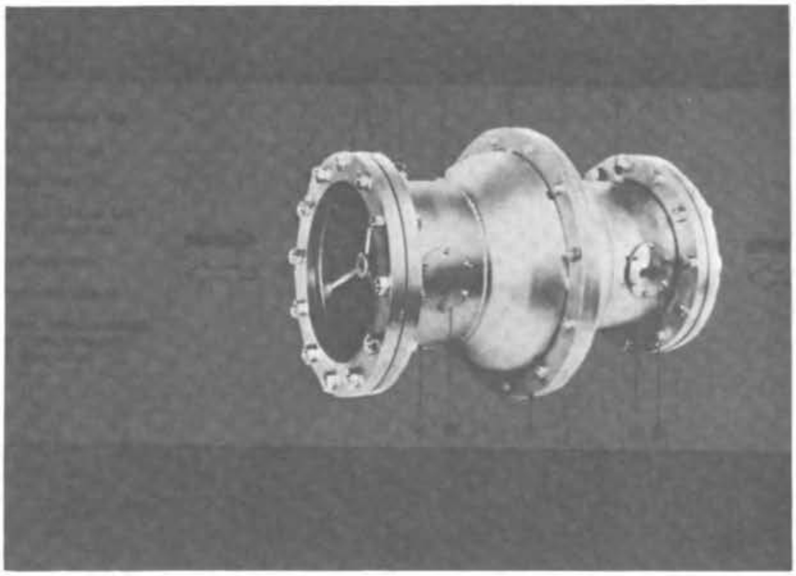


Fig. 71: Explosion barrier valve "Ventex"
Ø 200 to 400 mm

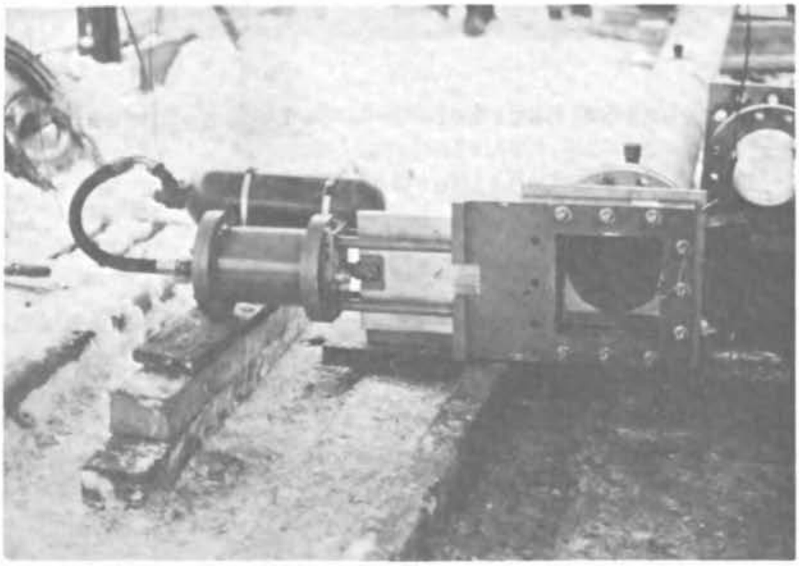
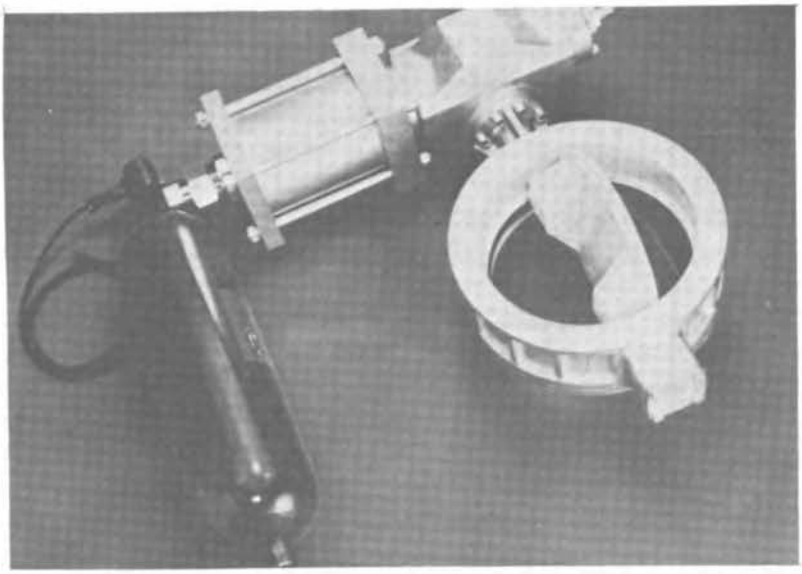
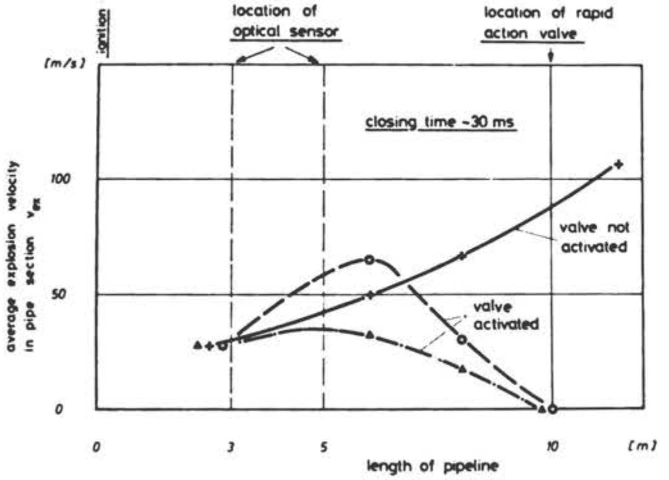


Fig. 72: Rapid action gate valve
200 x 200 mm on test rig



<u>Fig. 73</u>: Rapid action butterfly valve
Ø 400 mm



<u>Fig. 74</u>: Performance of a rapid action
valve Ø 400 mm against propane
explosions in pipelines

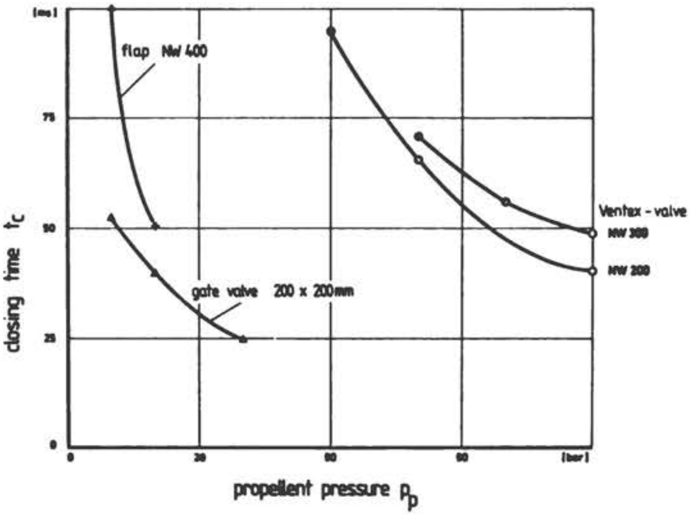


Fig. 75: Closing times of rapid action valves powered by compressed gas from pressurised containers

All types of valves have been tested under explosion conditions, against explosions of a propane/air-mixture. They gave satisfactory performance and completely prevented breakthrough of flames and sparks (fig. 74). They withstand an explosion pressure of at least 10 bar. They give also satisfactory performance as barrier devices against dust explosions.

The activation of the barrier devices described requires a certain minimum pressure. The distance between the sensor in the pipeline and the location where the barrier valve is installed depends on

a) the closing time

b) the expected explosion velocity.

It is therefore advisable to apply a sufficiently high propellant gas pressure so that the shortest possible closing time is obtained.

5. CONCLUSIONS FOR GRAIN ELEVATORS

Potential explosion hazards are always present in industrial installations where explosive mixtures are generated and have to be handled in the course of normal operations. Well known expamples are grinders, spray dryers, elevators, silos and bunkers, dust filters and separators. If ignition sources inherent to the equipment cannot be excluded with certainty - and experience demonstrates clearly that e.g. grinders, bucket elevators, chain and drag link conveyers, grinders, certain types of dryers are latent ignition sources - preventive measures against the initiation of explosions and/ or protective measures against the effects of explosions must be taken. A number of possibilities have been described in this paper. No general rules can be given for the selection of protective measures nor for the extent of protection nor for the degree of safety that should be aimed for. Decisions will have to be made on the basis of sound knowledge of explosion phenomena in general, of the explosion behaviour of the material handled in the plant in question and of the engineering details of the plant. When new installations are planned, explosion protection must be "designed in" right from the onset.

It will hardly be possible to completely adapt the existing grain elevators to the full scope of knowledge and experience available in the field of explosion protection today. The operating risk of an existing plant - even if modern explosion protection is applied wherever possible - will always be higher than for a new plant, for which the design activities, including explosion protection, will start tomorrow.

It is recommended to scrutinize meticulously the existing grain elevators for possible ignition and explosion hazards, and to decide on the protective measures required for each part, in the light of the local situation, with priority for the protection of human lives. The decision on the level of risk to be accepted should be based on a consent between plant engineer, explosion safety expert, and plant management.

A basic requirement is to keep the whole installation free from settled down dust. This measure will prevent that a small local exploison of flash fire can trigger a much more dangerous and devastating secondary explosion, by whirling up settled dust.

An other basic requirement is to ensure good bonding and earthing of all metal parts, to prevent buildup of electrostatic charges. Ground resistance should be measured at regular intervals.

Analysis of incident reports indicates, that bucket elevators, chain- or drag-link conveyors and similar types of conveyors must be regarded as latent ignition sources (e.g. mechanical friction, hot bearings etc.). Explosive dust/air-mixtures may always be present within such conveyors. Due to the geometrical shape of elevators - very long casings - and the conveying elements inside (creating high turbulence), it must be expected that after ignition, combustion will rapidly develop into an extremely violent explosion or even a detonation. To cope with this hazard, the following measures will have to be considered:

- tightly sealed casing with nitrogen inertisation and continuous monitoring of oxygen concentration
- pressure resistant or pressure shock resistant casings - round, not square shaped - designed for a nominal pressure of 10 bar. Closure of top and bottom ends either by rotary valves that will automatically stop in case of an explosion, by detector activated rapid action valves, or by suppression barriers
- installation of sectional suppression barriers for explosions in both directions over the full length of the elevator leg.

This is by no means a comprehensive compilation. Effective explosion protection on the elevator leg will prevent with a high degree of certainty that an explosion originating in the leg can propagate into the silo.

If an explosion occurs in a silo, it is almost certain that it will propagate into other silos as well, since they are interconnected by dust aspiration and separation systems, conveying equipment etc. Possible protective measures are

- design of the roof of a silo for explosion pressure relief; the entire roof area will have to serve for this
- installation of barrier devices or suppression barriers in all aspiration or dust extraction lines.

Since, in existing grain elevators, it will hardly be possible to use the entire top area for explosion pressure relief, it is essential to install at least effective explosion barriers in order to confine an explosion to one silo only.

Last but not least, it must be emphasized, that "trivial" ignition sources, i.e. unauthorised smoking, welding and torch cutting without proper permit, must be excluded by strict organisational measures.

These recommendations are far from complete. For existing elevators, a comprehensive list of suggestions for explosion protection can only be compiled after a thorough inspection of the entire installation and - depending on the case - possibly some explosion tests with critical parts. However, it is our firm conviction, that know-how and experience available today would permit a substantial reduction of the operating risk of existing elevators, and that new installations can be designed for an optimum degree of safety.

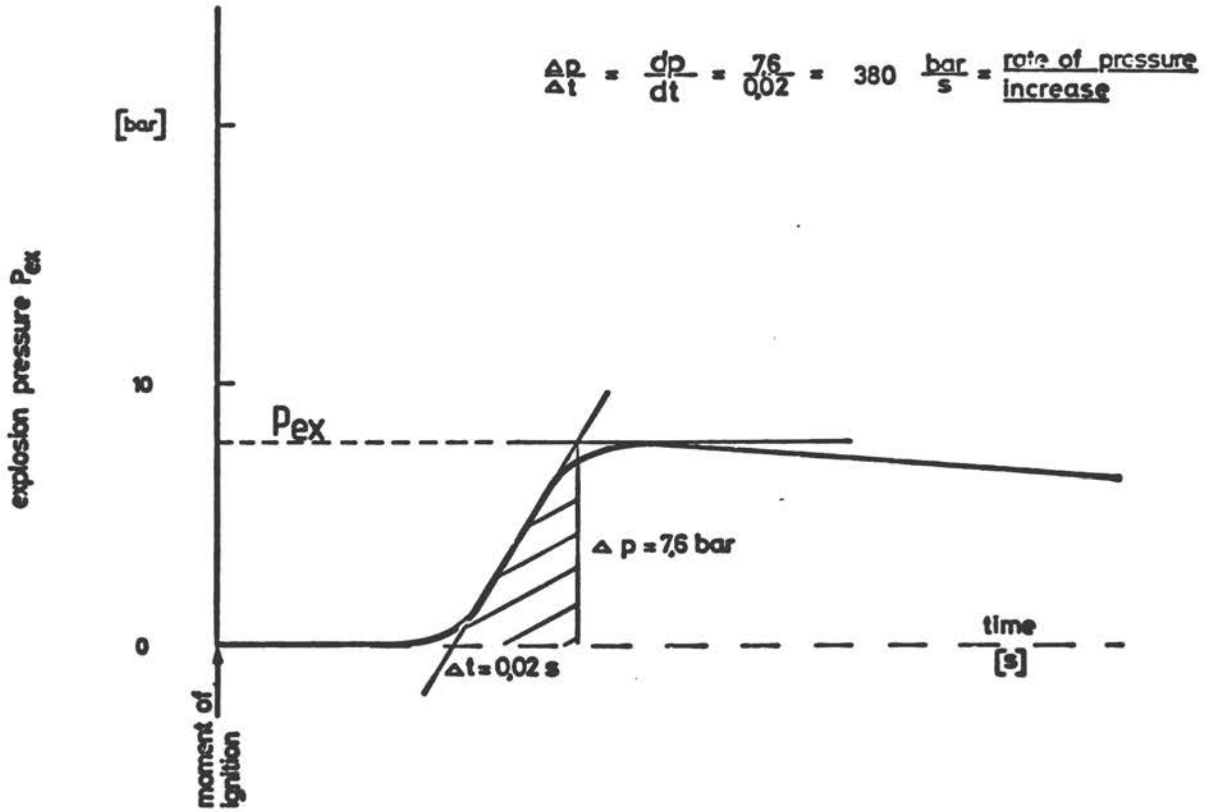
6. REFERENCES

All references given hereafter are publications in German. The English translation of the titles is given in brackets.

Bartknecht, W:	Explosionen, Ablauf und Schutzmassnahmen (Explosions, cause and cure) Springer Verlag Berlin, Heidelberg, New York (Juli 1978)
Beck, A.J.:	Dokumentarische Erfassung von Staubexplosionen (Documentation on dust explosions) "Die Berufsgenossenschaft" Heft 10 (Oktober 1974)
Siwek, R:	20 l-Laborapparatur für die Bestimmung der Explosionskennzahlen brennbarer Stäube (20 litre laboratory test apparatus for the determination of explosion data of combustible dusts) Ciba-Geigy AG/Ingenieurschule Winterthur (September 1977)
VDI-Berichte:	Brennbare Industriestäube (Combustible industrial dusts) Band 19, 1957
VDI-Berichte:	Verhütung von Staubbränden und Staubexplosionen (Prevention of dust fires and dust explosions) Band 165, 1971
VDI-Berichte:	Sichere Handhabung brennbarer Stäube (Safe handling of combustible dusts) Band 304, 1978
VDI-Richtlinie 3673:	Druckentlastung von Staubexplosionen (Pressure relief of dust explosions) VDI-Verlag Düsseldorf, 1978

Bartknecht W.: Die Schutzmassnahme "Explosionsunterdrückung"
(The Protective Measure "Explosion suppression")
Der Ladenburger Kreis, Nr. 50, 1977,
Schrift der Firma Total Foerstner & Co, Ladenburg

Bartknecht W.: Automatische Löschmittelsperre
(Automatic suppression barrier)
Der Ladenburger Kreis, Nr. 51, 1977, Schrift der
Firma Total Foerstner & Co, Ladenburg

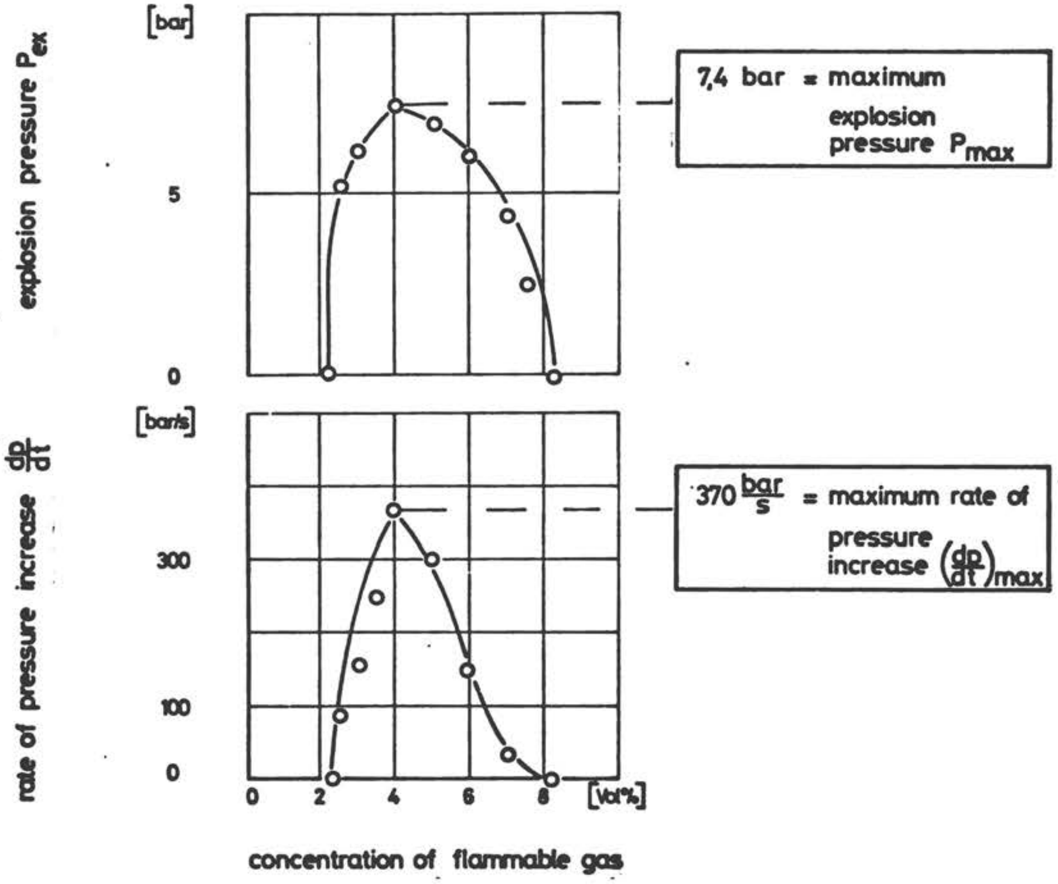


CIBA – GEIGY

SICHERHEITSDIENST

Bestimmung des zeitlichen Druckanstieges einer Brenngasexplosion

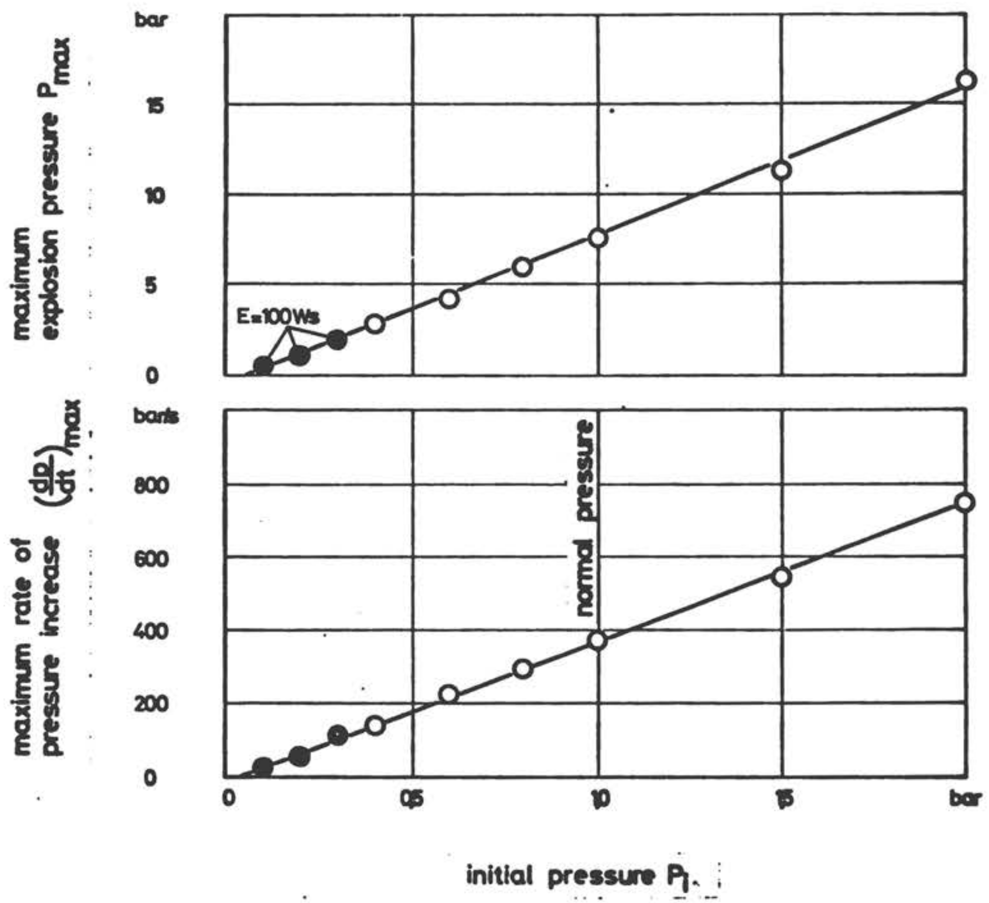
Bt 240/74



7,4 bar = maximum explosion pressure P_{max}

$370 \frac{bar}{s}$ = maximum rate of pressure increase $\left(\frac{dp}{dt}\right)_{max}$

CIBA - GEIGY SICHERHEITSDIENST	Abhängigkeit der Explosionskennzahlen von der Brenngaskonzentration (V=7 l)	**Bt 241/74**



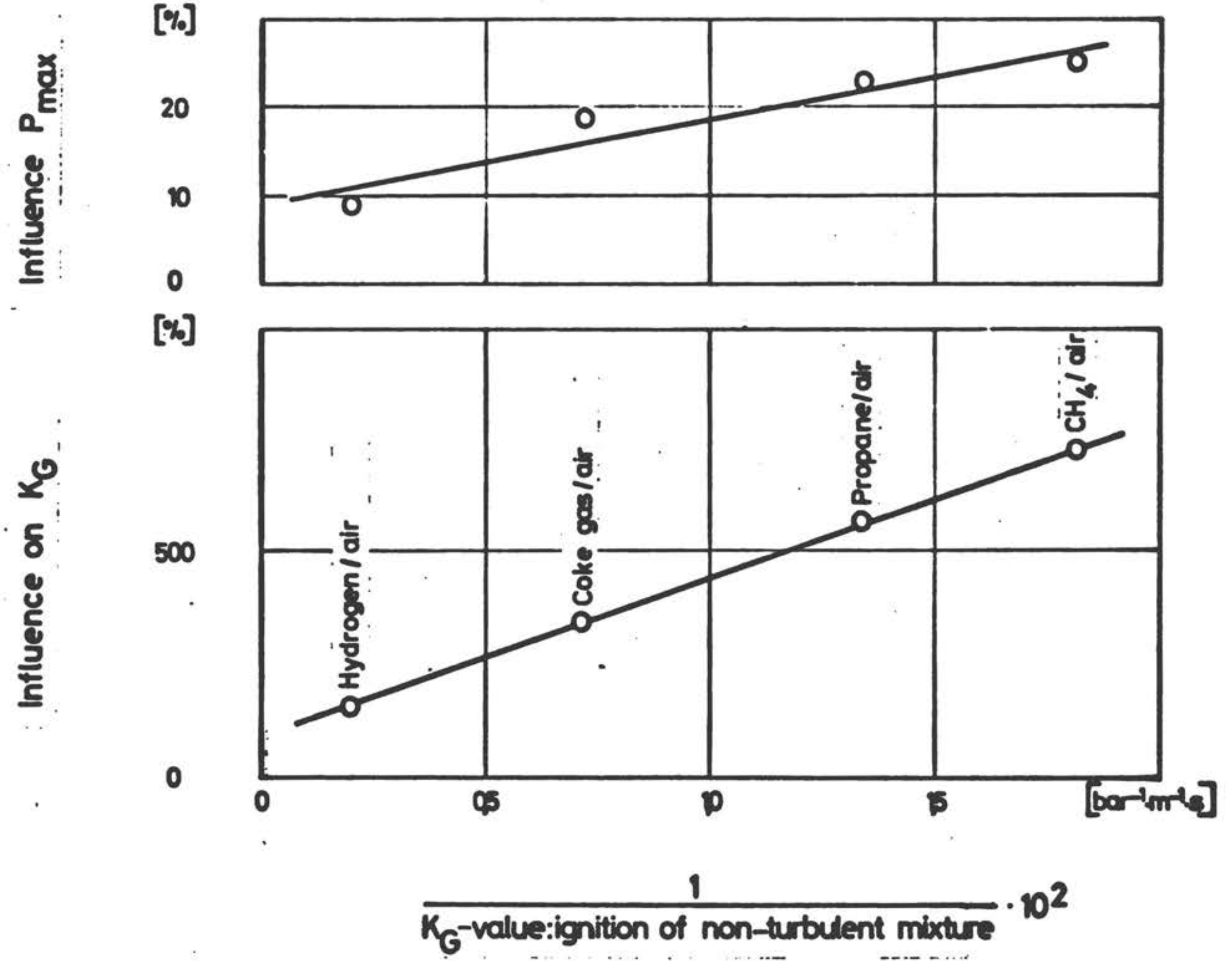
CIBA - GEIGY

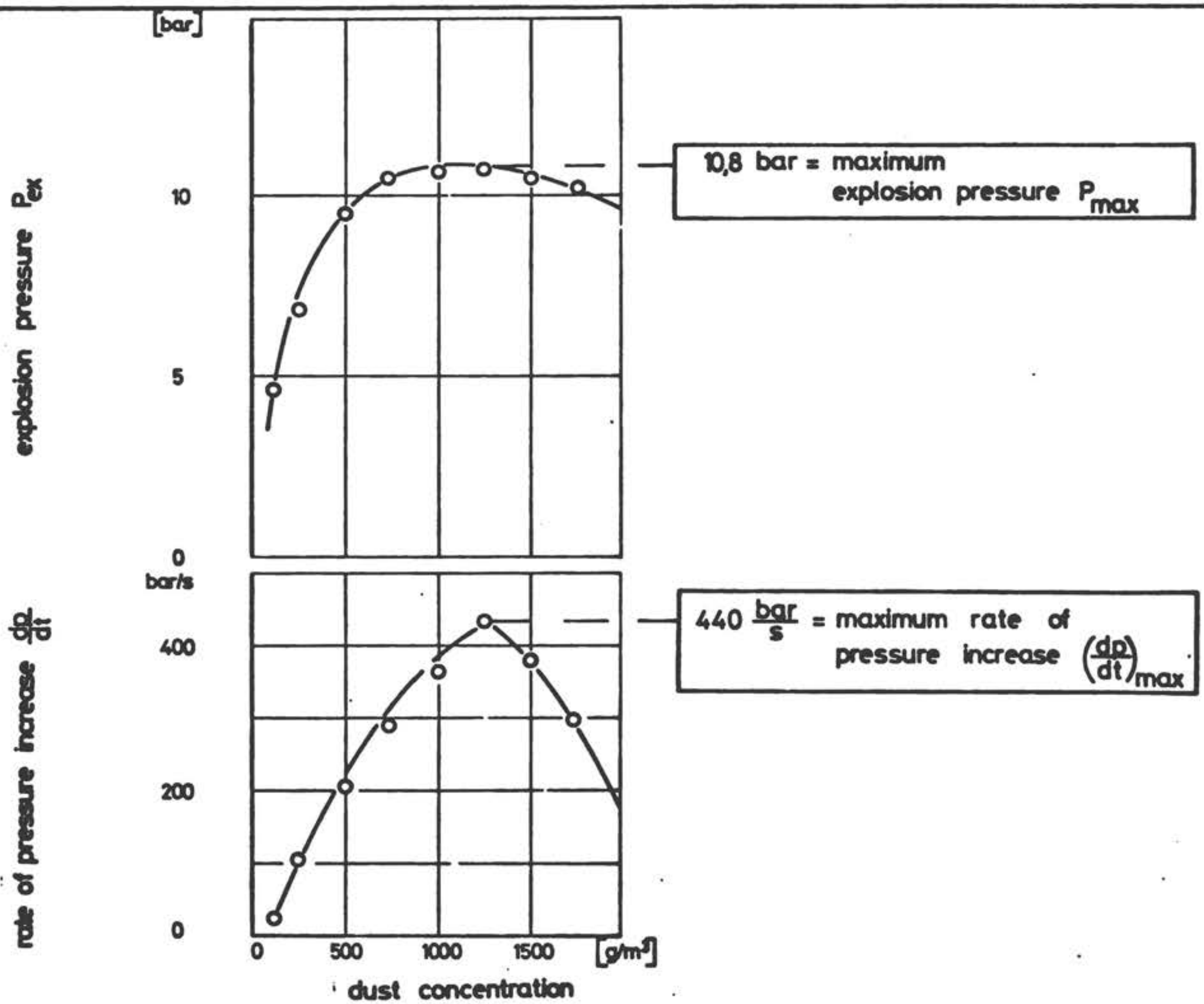
SICHERHEITSDIENST

Explosionskennzahlen von Propan

7 l-Behälter / E=10 Ws

Bt 243/74

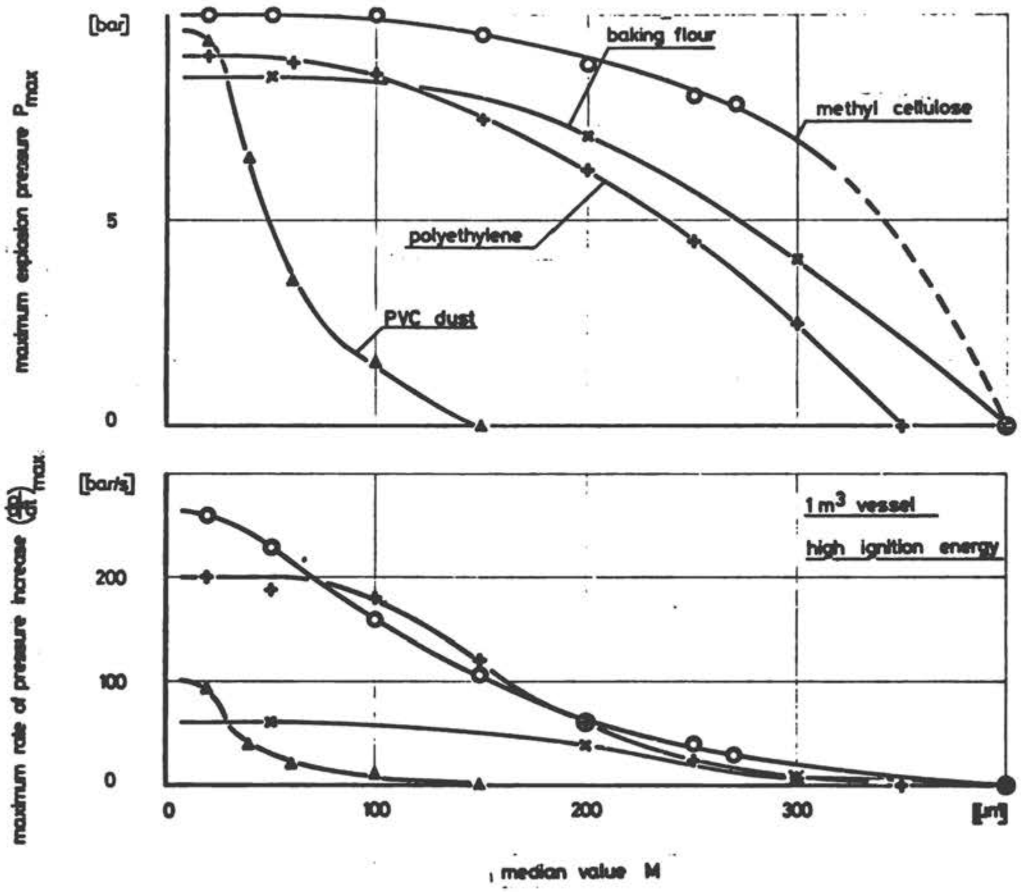

Influence P_{max}
[%]
20
10
0
Influence on K_G
[%]
500
0
Hydrogen / air
Coke gas / air
Propane/air
CH_4 / air
0
0,5
1,0
1,5
[$bar^{-1} m^{-1} s$]
$\frac{1}{K_G\text{-value: ignition of non-turbulent mixture}} \cdot 10^2$



10,8 bar = maximum explosion pressure P_{max}

440 $\frac{bar}{s}$ = maximum rate of pressure increase $\left(\frac{dp}{dt}\right)_{max}$

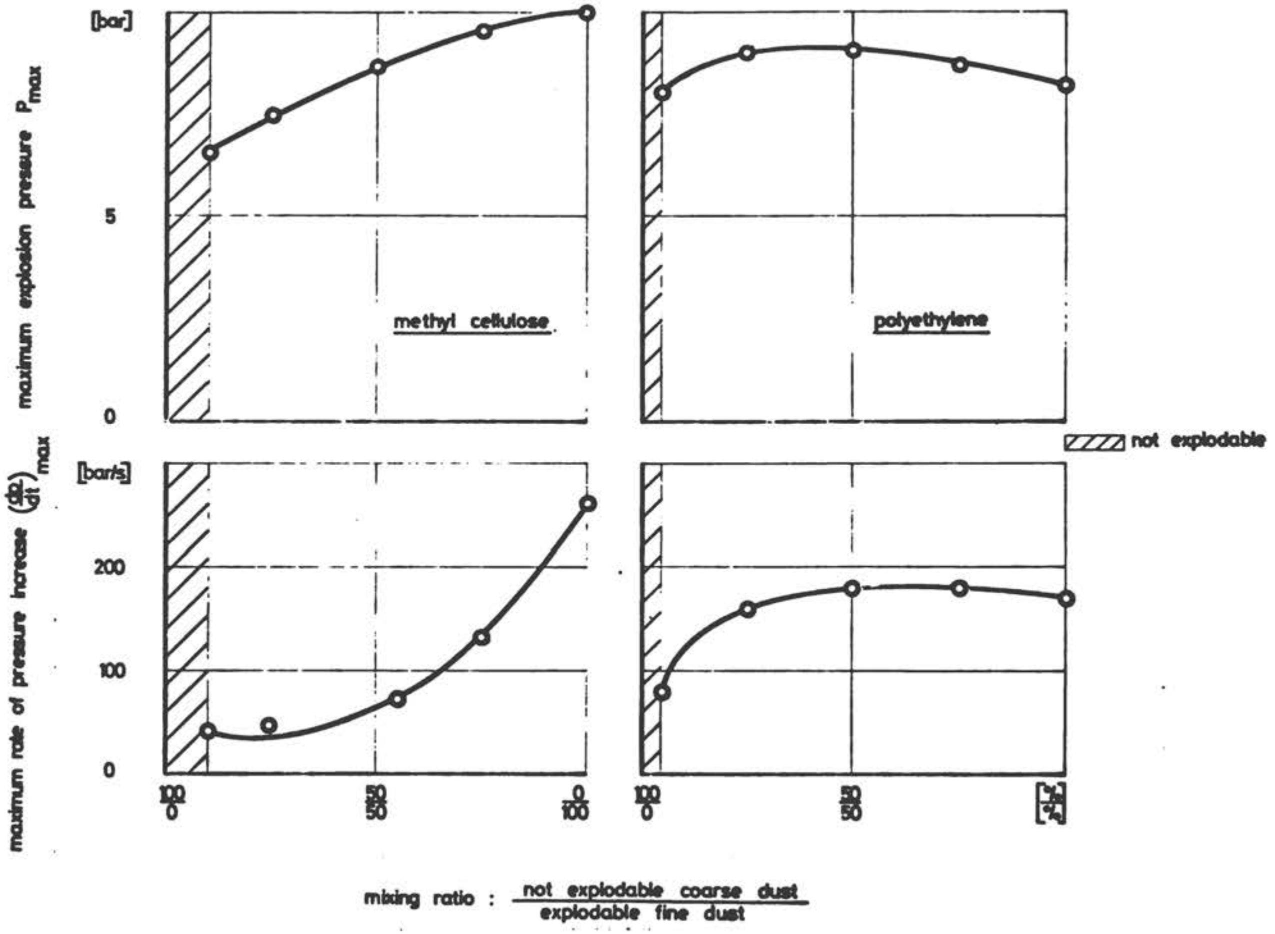
CIBA - GEIGY SICHERHEITSDIENST	Abhängigkeit der Explosionskennzahlen von der Staubkonzentration (1 m³ - Behälter)	Bt 239/74



CIBA-GEIGY
SICHERHEITSDIENST

Einfluss der Korngrösse auf die
Explosionskennzahlen von Stäuben

Bt 271/74



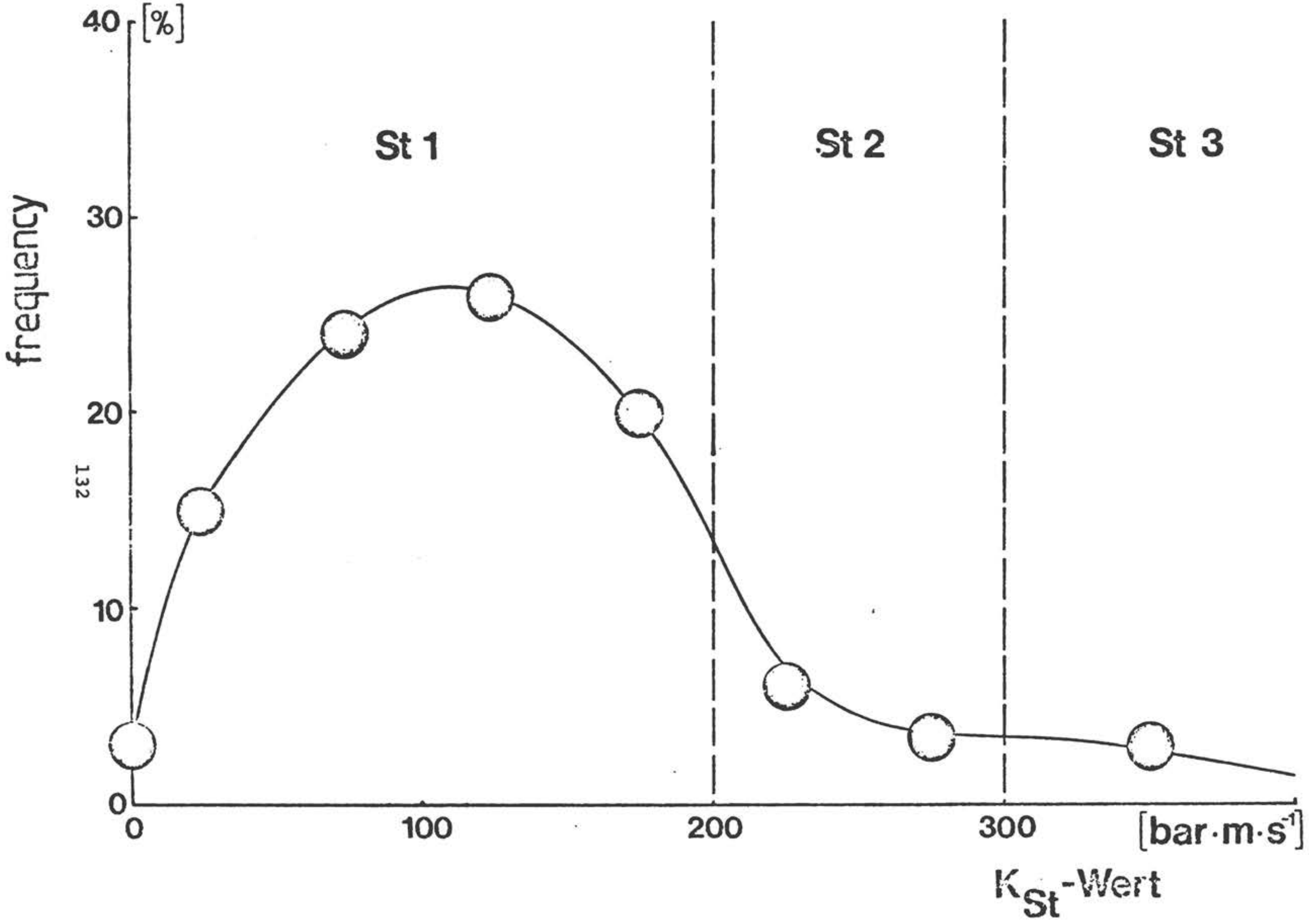
CIBA – GEIGY

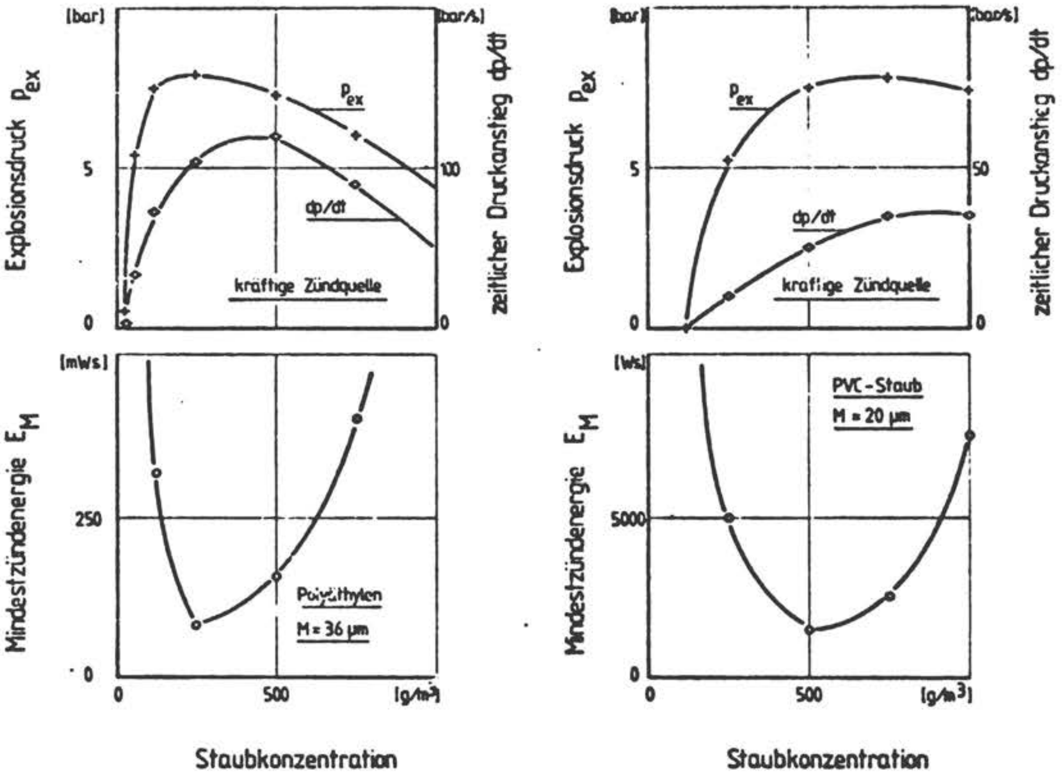
SICHERHEITSDIENST

Explosionskennzahlen von Staubmischungen

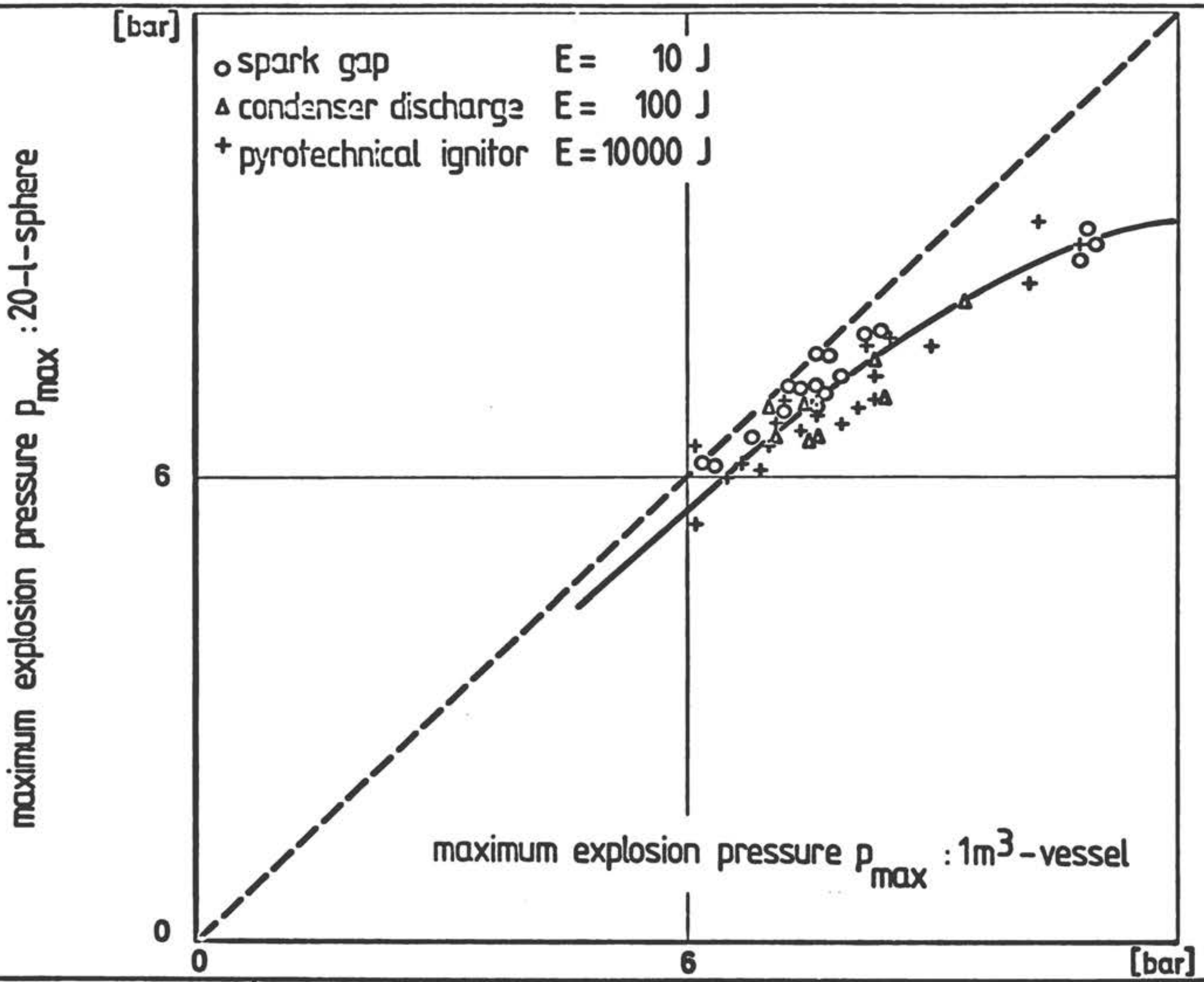
1m^3-Behälter / kräftiges Zündinitial

Bt 272/74

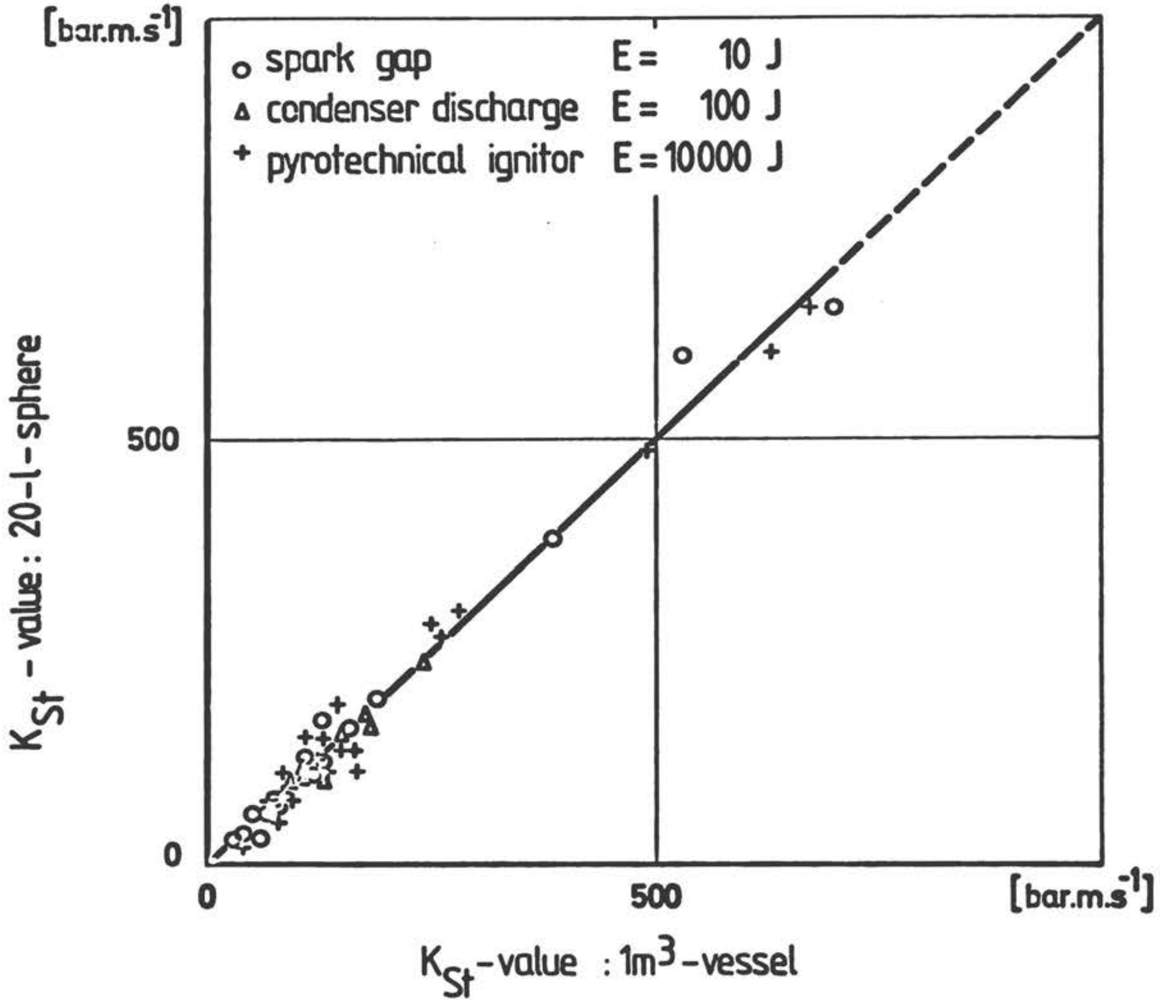

40
30
20
10
0
[%]
frequency
St 1
St 2
St 3
0
100
200
300
[bar·m·s⁻¹]
K_{St}-Wert



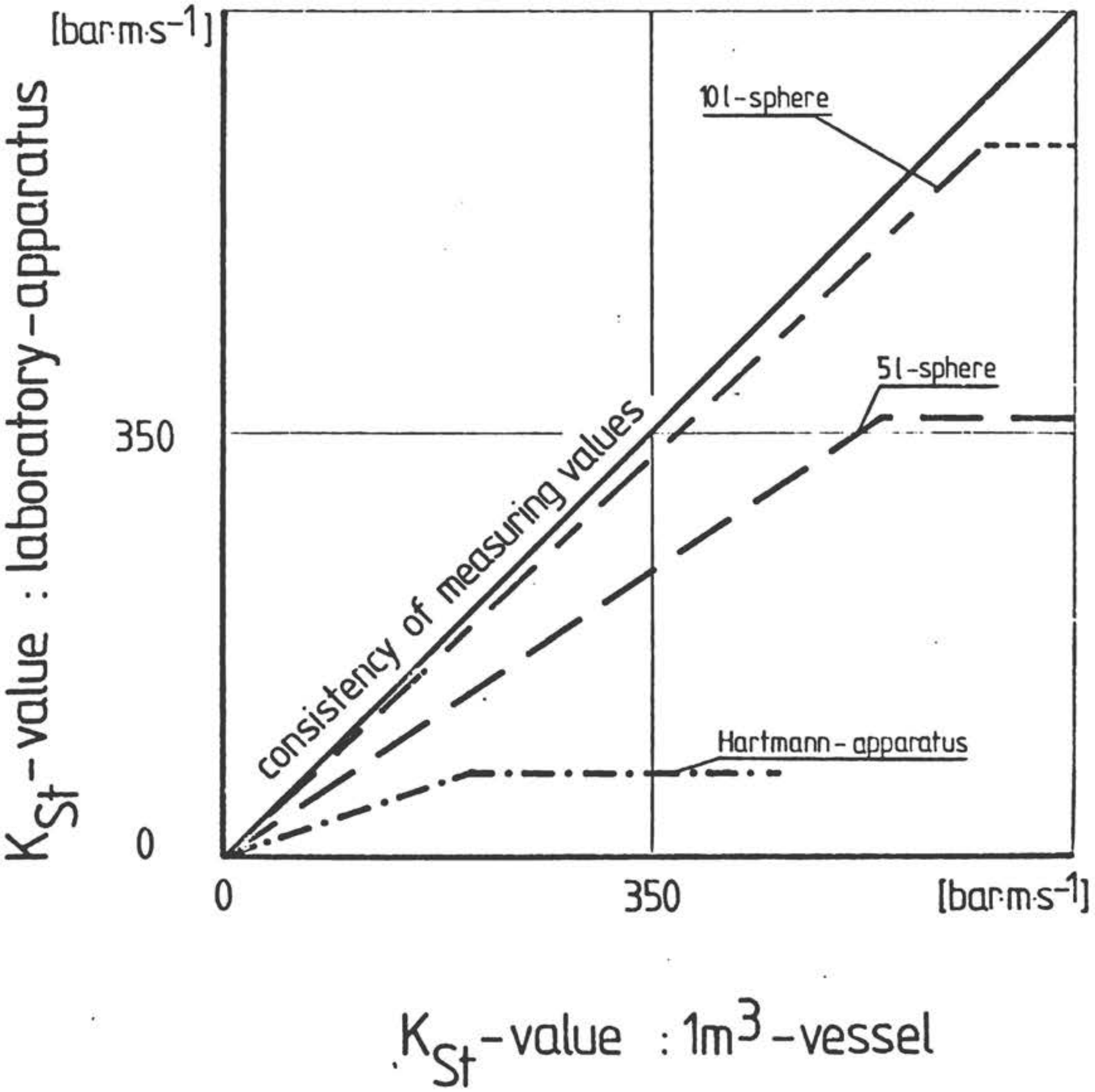
CIBA - GEIGY SICHERHEITSDIENST	Explosionskennzahlen von Kunststoff-Stäuben 1m³ - Behälter	Bt 24/77



CIBA – GEIGY SICHERHEITSDIENST	Maximaler Explosionsdruck P_{max}: Vergleich 1 m³ – Behälter / Laborapparatur	Bt 16/77

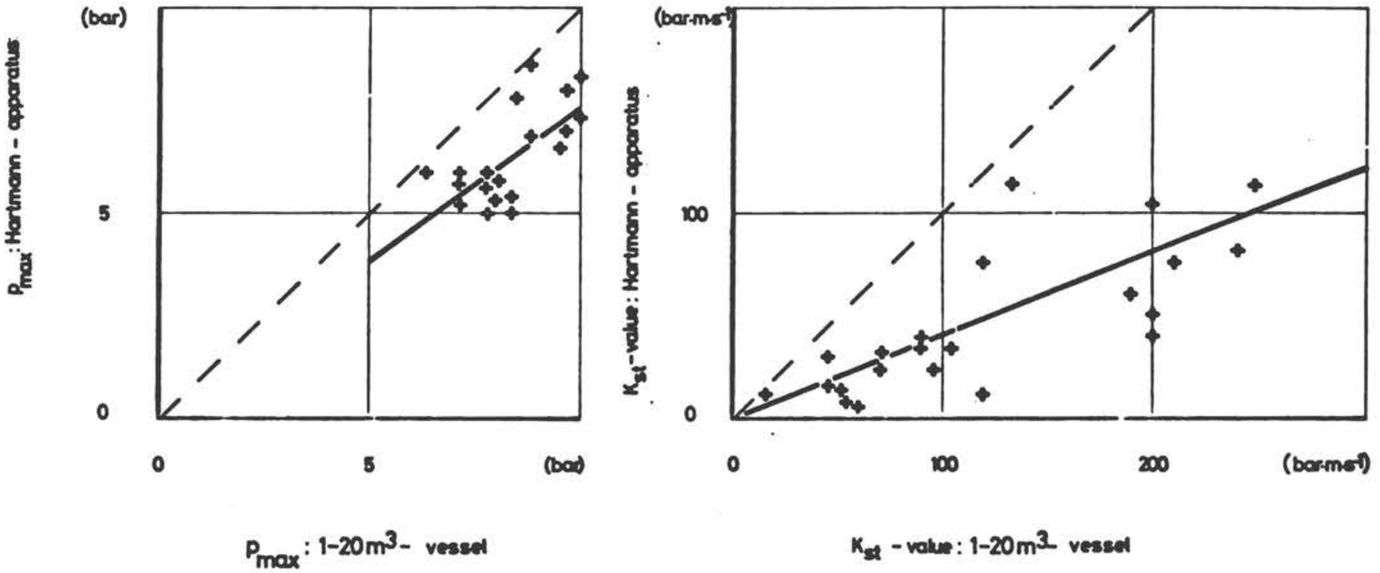


CIBA-GEIGY SICHERHEITSDIENST	K_{st} -Wert : Vergleich: 1 m^3 – Behälter / Laborapparatur	Bt 17/77

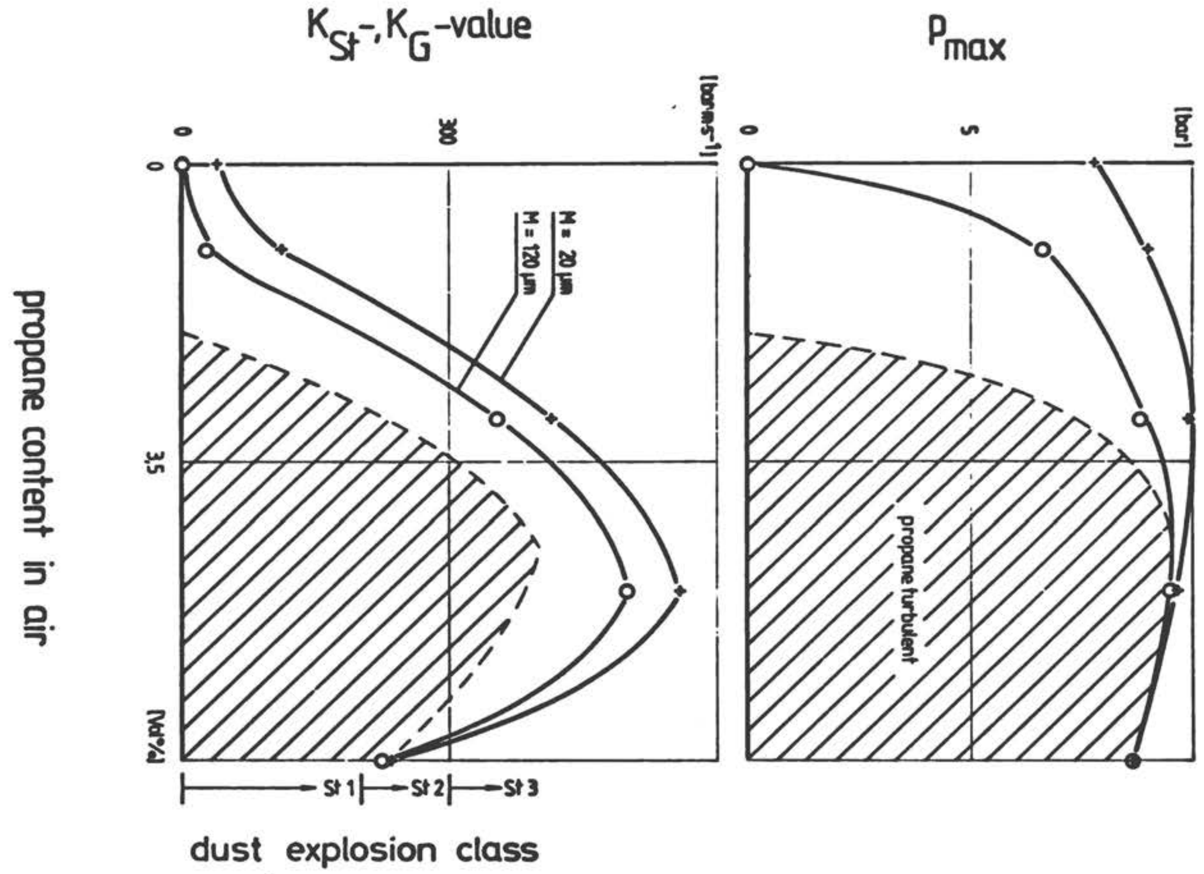


Vergleich: der Kennzahlen in verschiedenen Laborapparaturen
[$E = 10$ Ws , $p_v = 1$ bar (absolut)]

ignition : spark gap



CIBA - GEIGY SICHERHEITSDIENST	Explosionskennzahlen : Stäube Hartmann -Apparatur/Grossbehälter	Bt 201/75



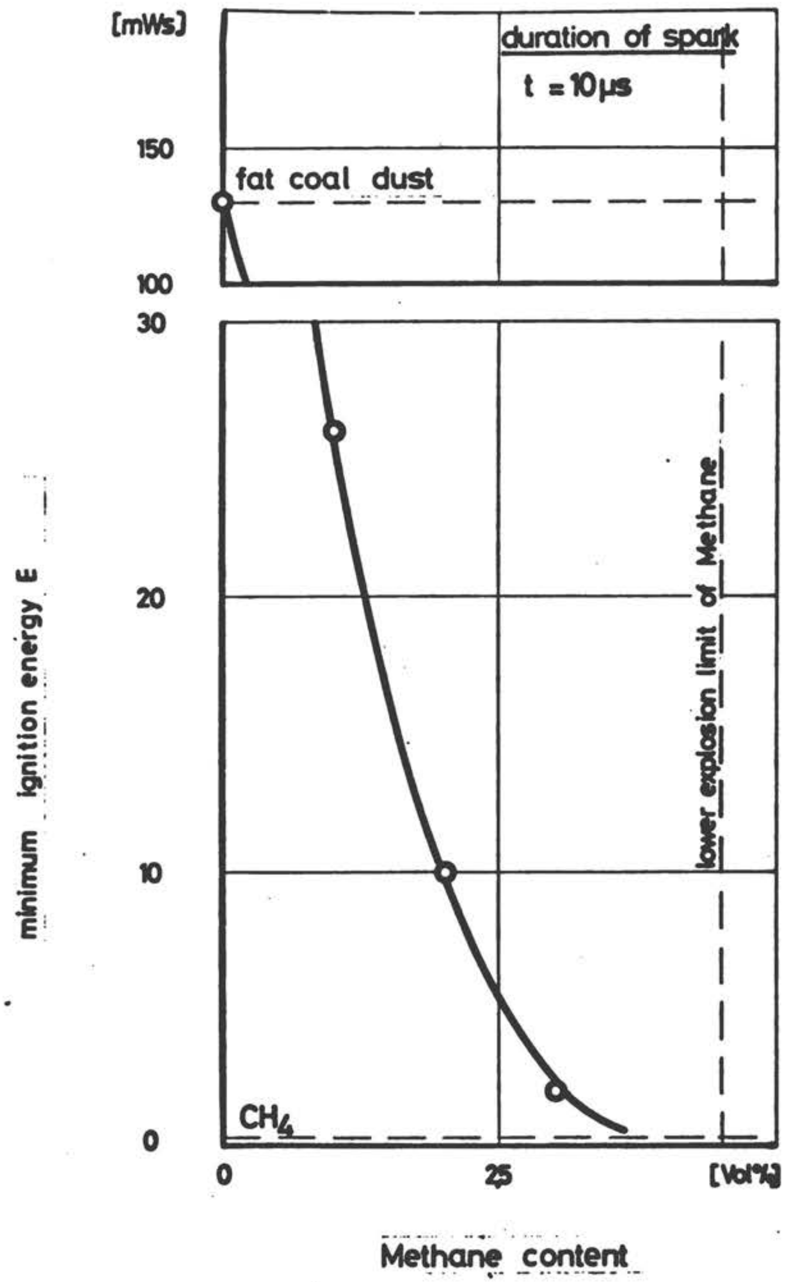
CIBA - GEIGY

SICHERHEITSDIENST

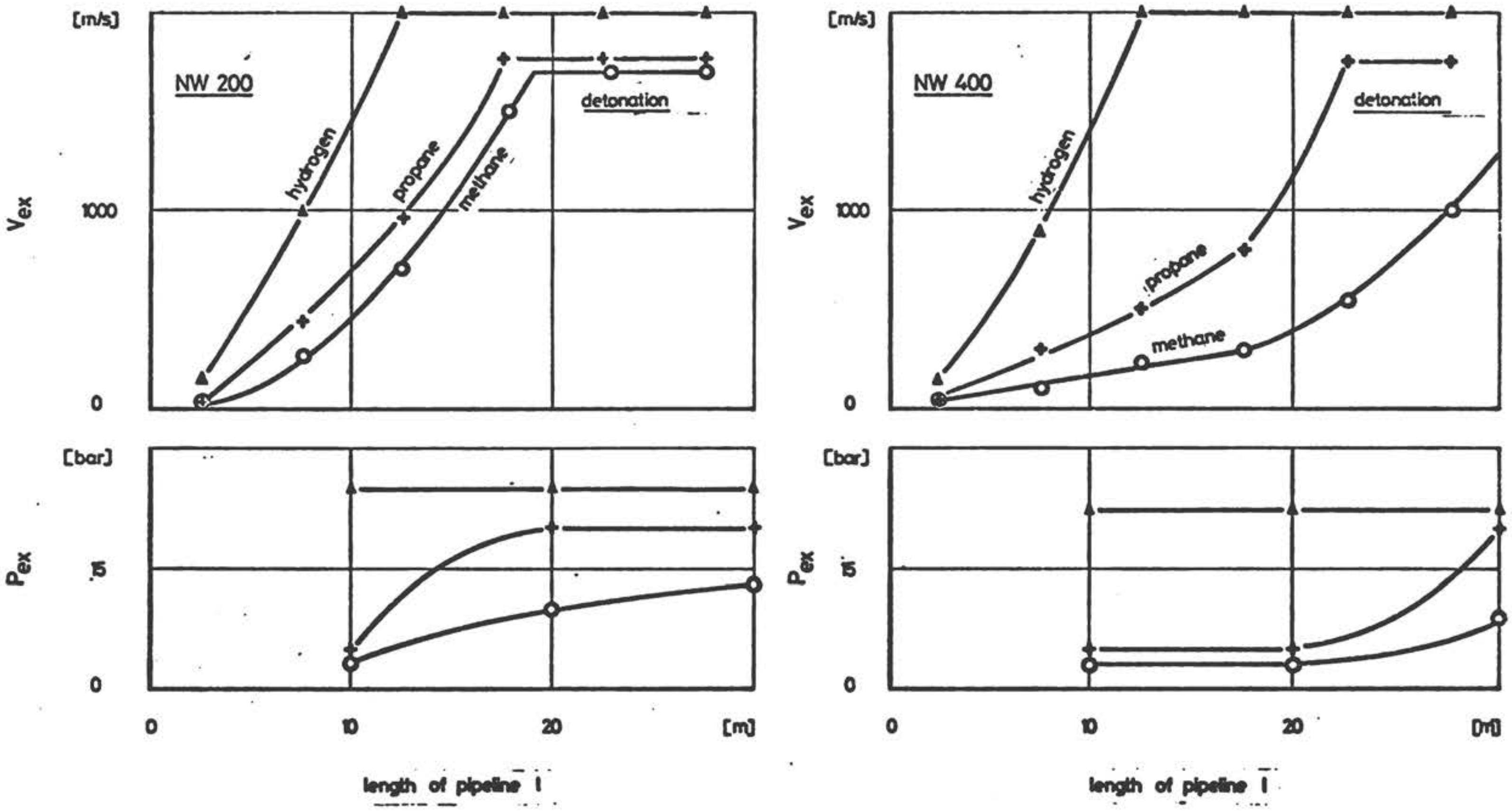
Explosionskennzahlen von hybriden Gemischen aus PVC-Staub und Propan

$1 m^3$-Behälter, kräftige Zündquelle

Bt 22/77



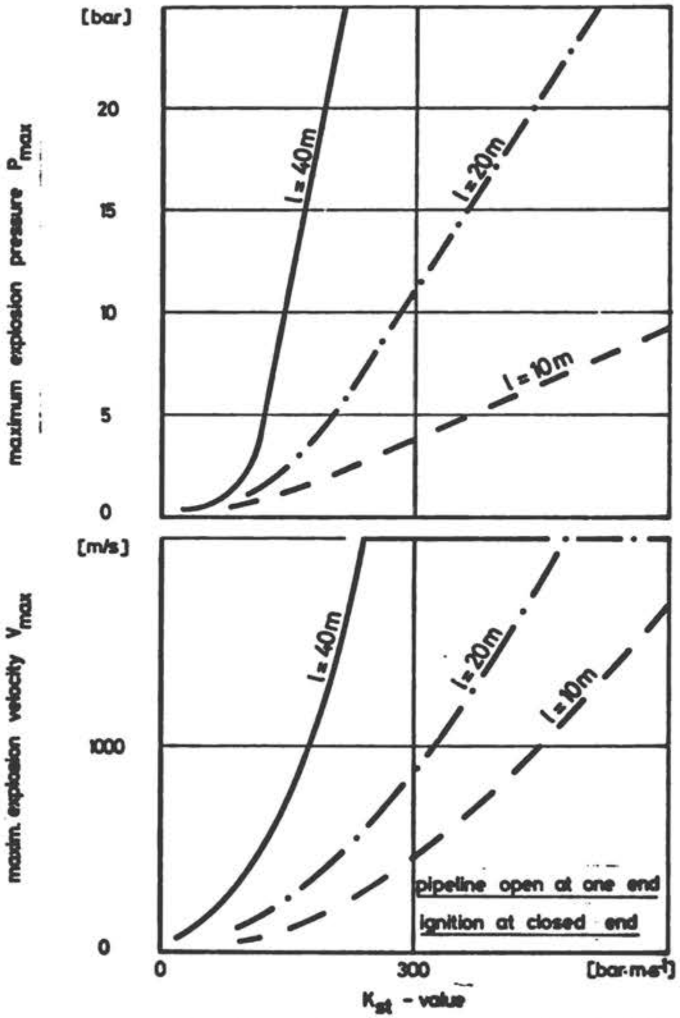
according to Franke (1974)



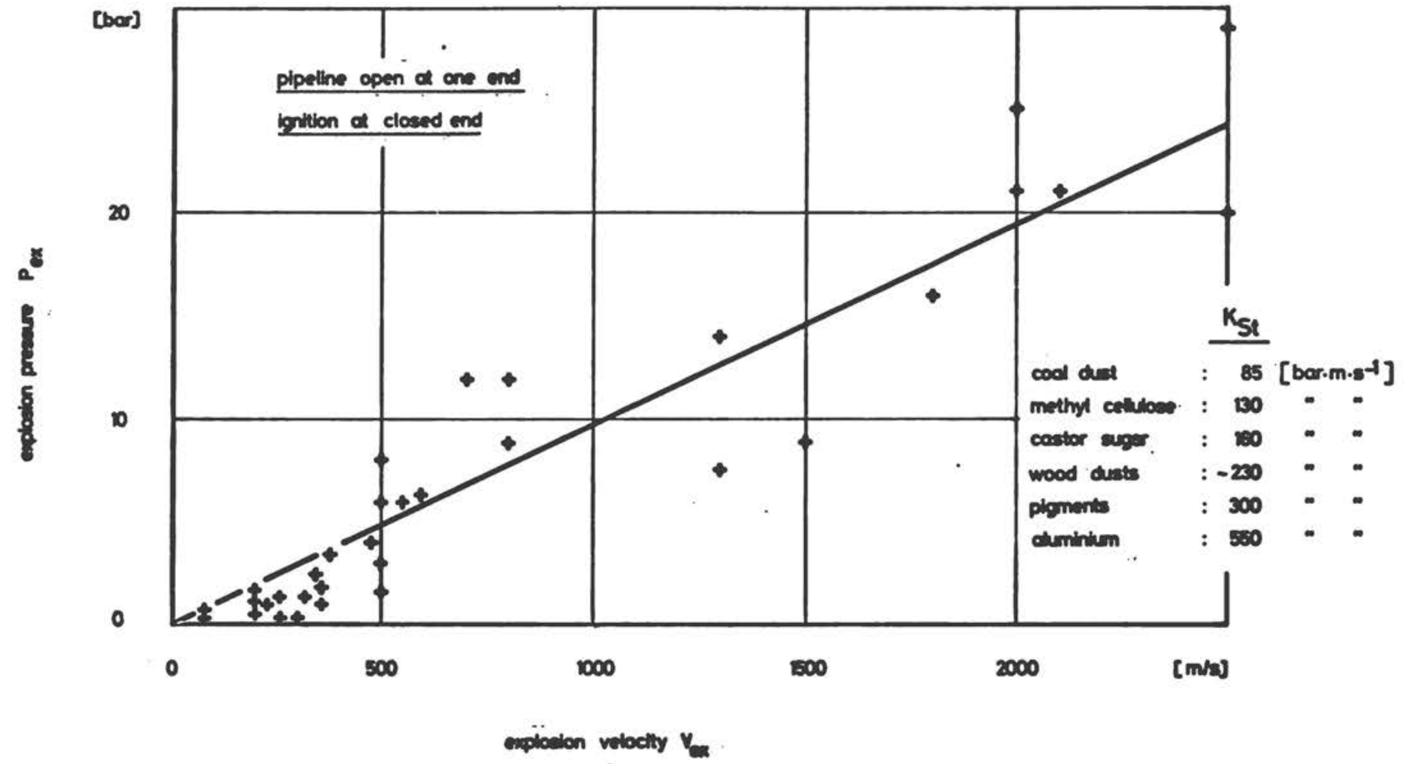
CIBA-GEIGY
SICHERHEITSDIENST

Rohre : Flammenstrahlzündung in turbulentes Ge=
misch Rohrleitung einseitig geschlossen

Bt 294/75



CIBA-GEIGY SICHERHEITSDIENST	Explosionskennzahlen von Staubexplosionen in Rohrstrecken NW 400 Flammenstrahlzdg.	**Bt 297/75**



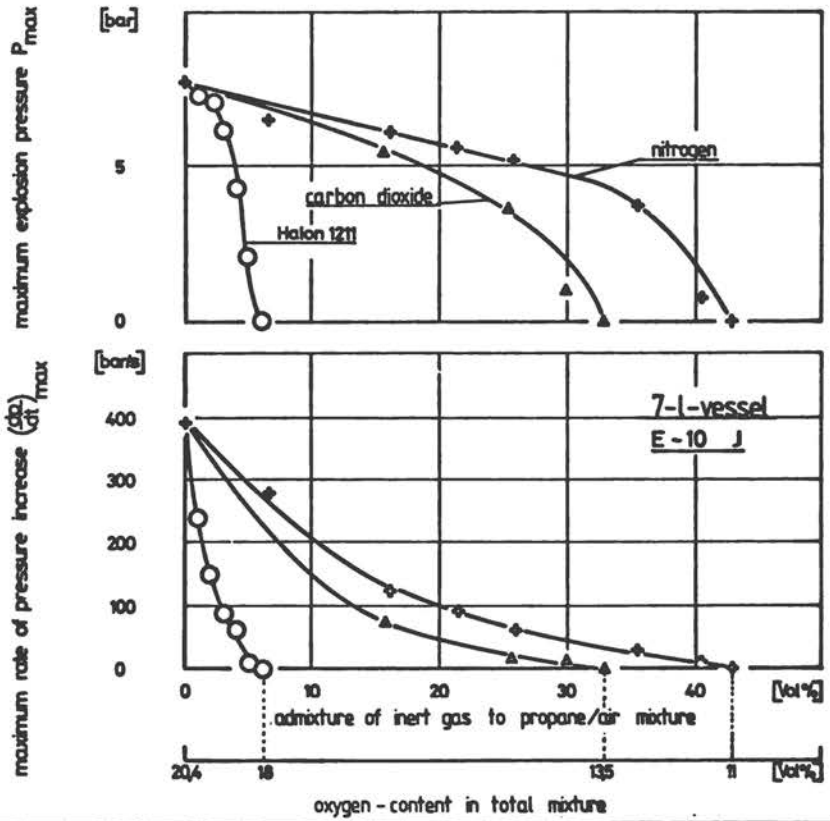
CIBA-GEIGY

SICHERHEITSDIENST

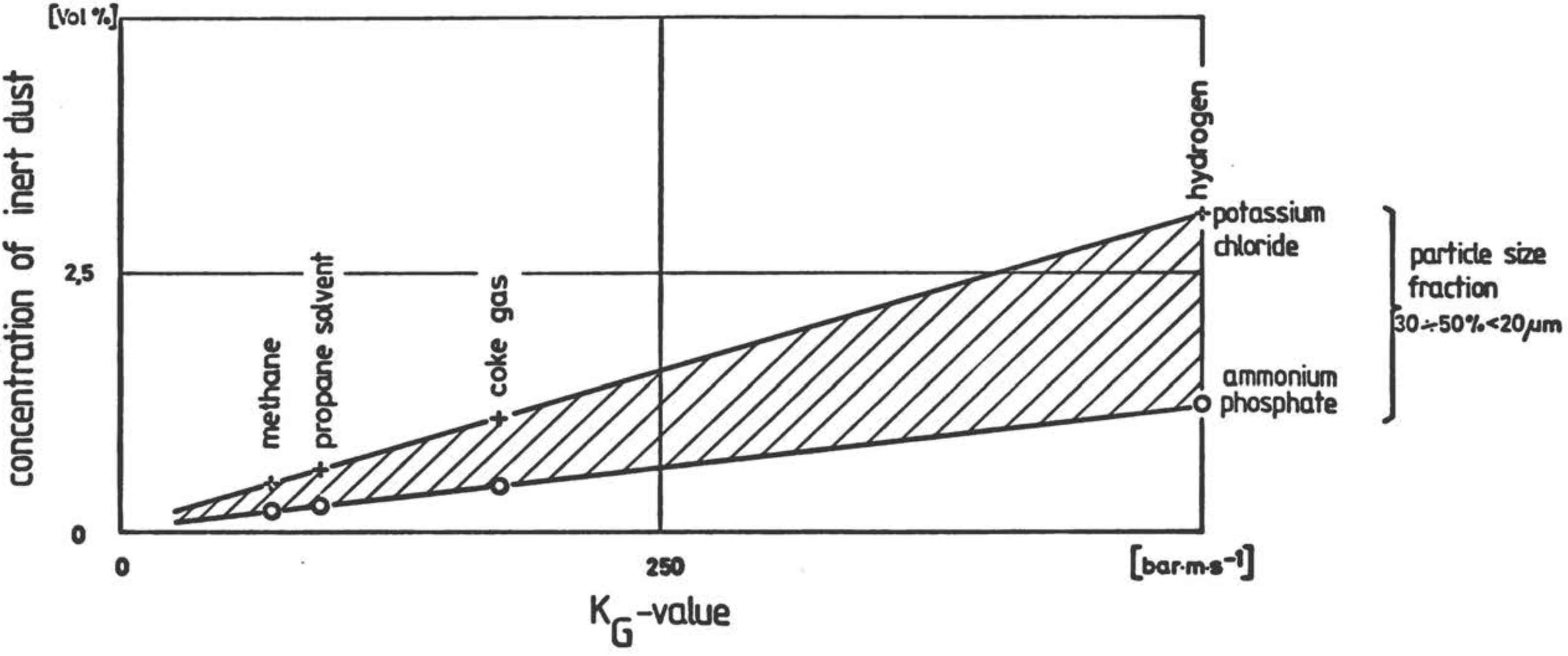
Stäube : NW 400

$(p_{ex})_m = f(v_{ex})$

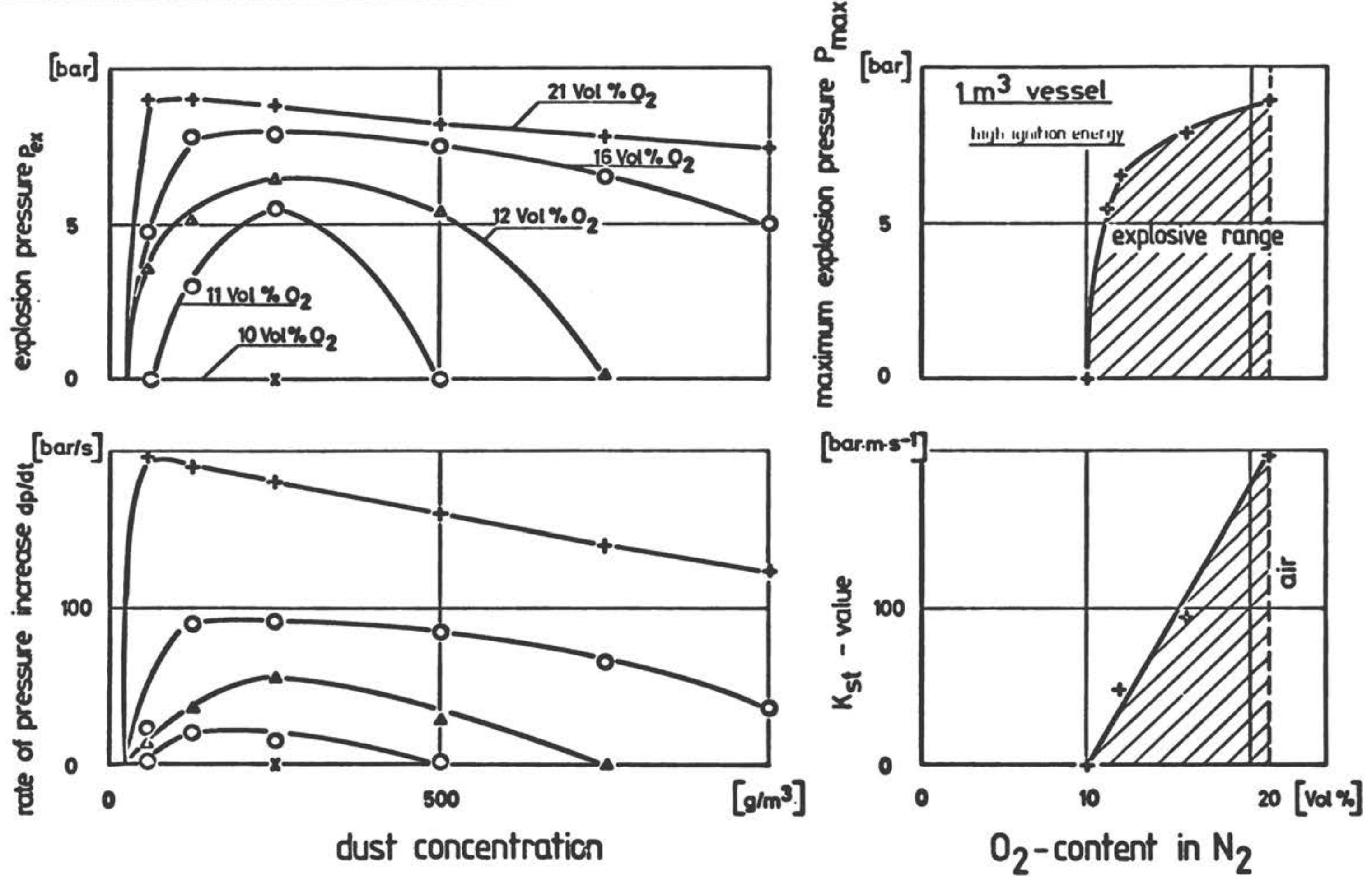
Bt 298/75



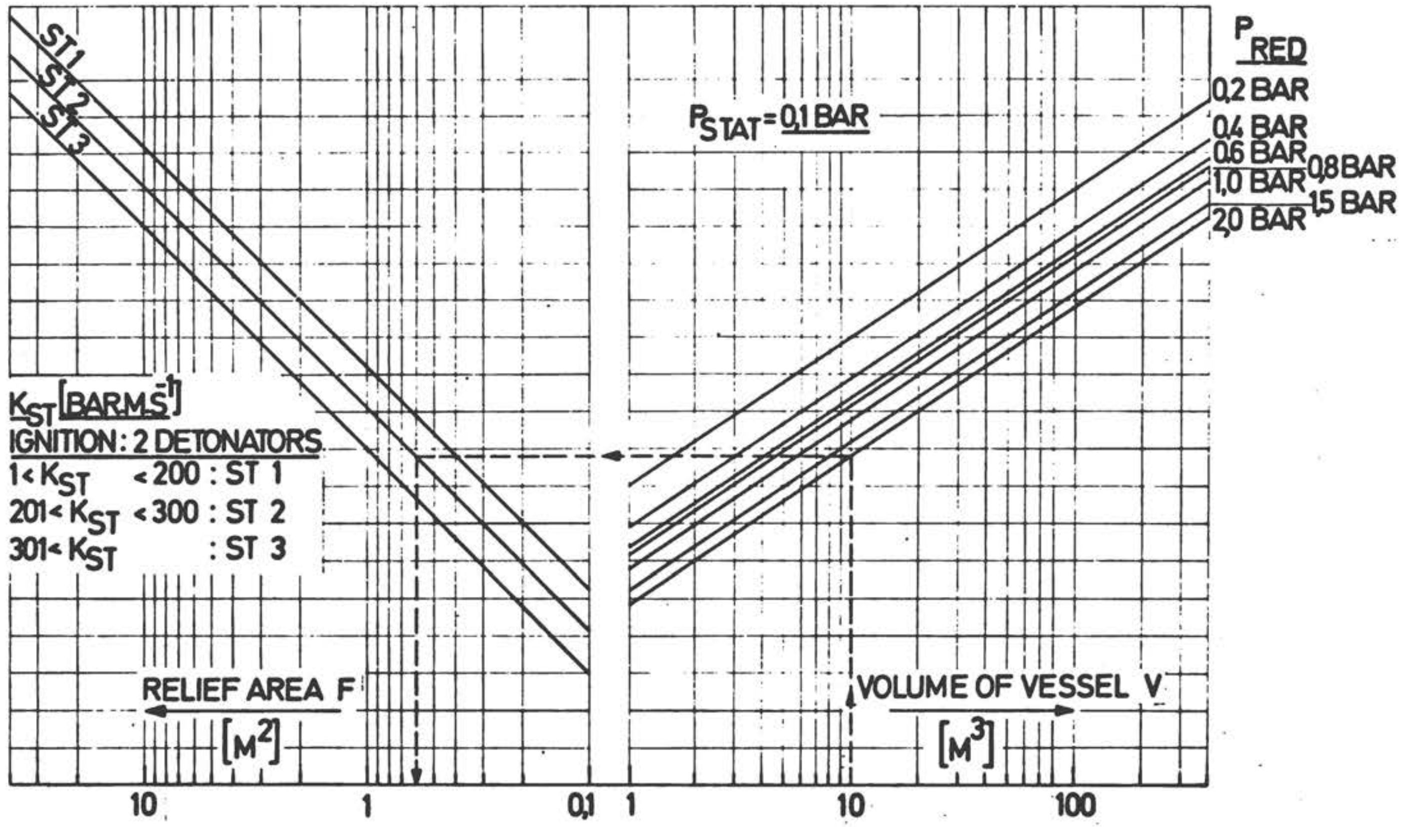
CIBA - GEIGY SICHERHEITSDIENST	Inertisierung von Propan/Luft - Gemischen	**Bt 56/74**



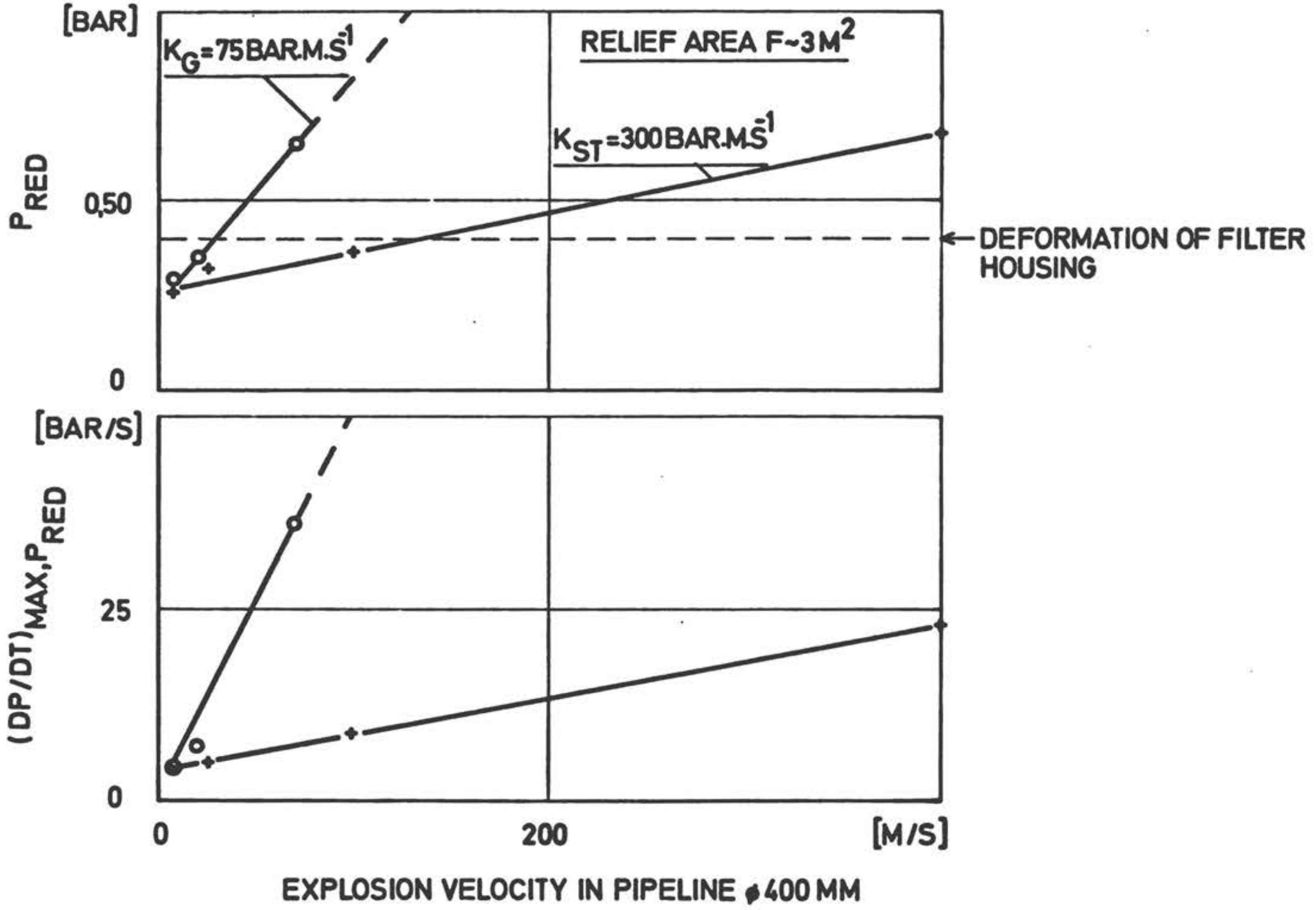
CIBA-GEIGY SICHERHEITSDIENST	**Inertisierung von Brenngasen** **durch Trockenlöschpulver** **E = 10Ws**	**Bt 19/76**



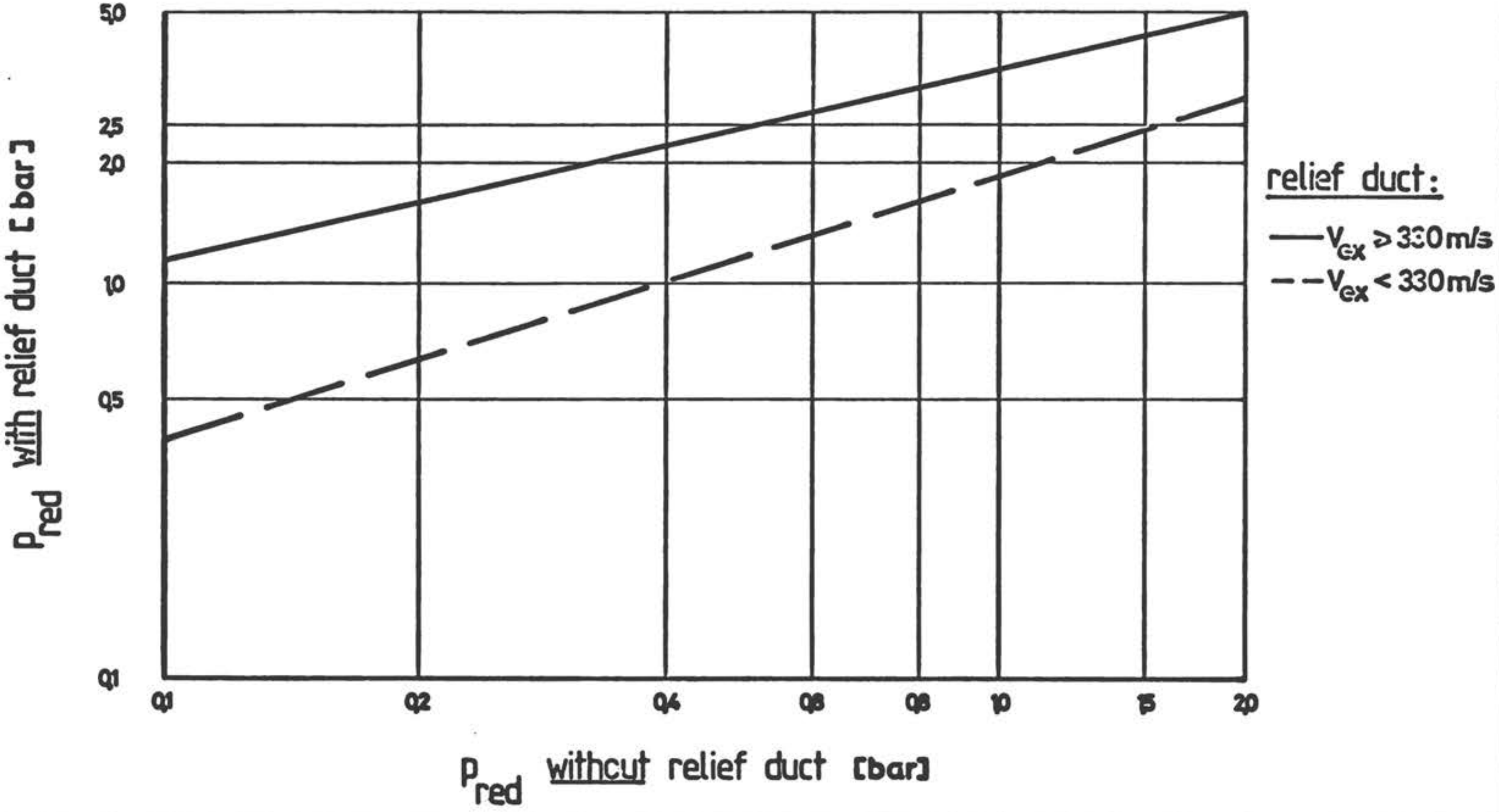
CIBA-GEIGY SICHERHEITSDIENST	**Inertisierung von Polyäthylenstaub** **(M = 25 µm) durch Stickstoff**	**Bt 20/76**



CIBA-GEIGY SICHERHEITSDIENST	Explosionsdruckentlastung : Stäube	Bt 302/73



CIBA - GEIGY SICHERHEITSDIENST	Schlauchfilter ohne Einbauten Flammenstrahlzündung	Bt 213/76

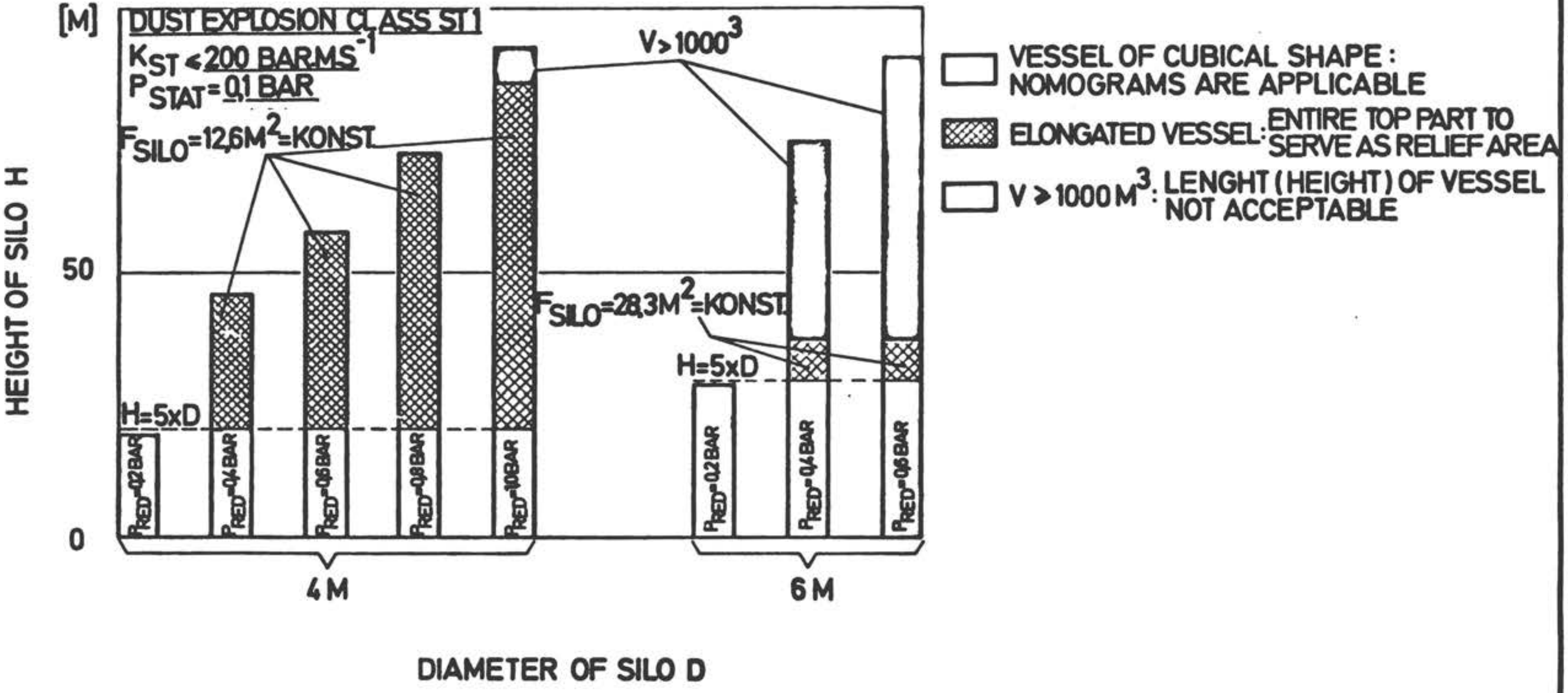


CIBA – GEIGY

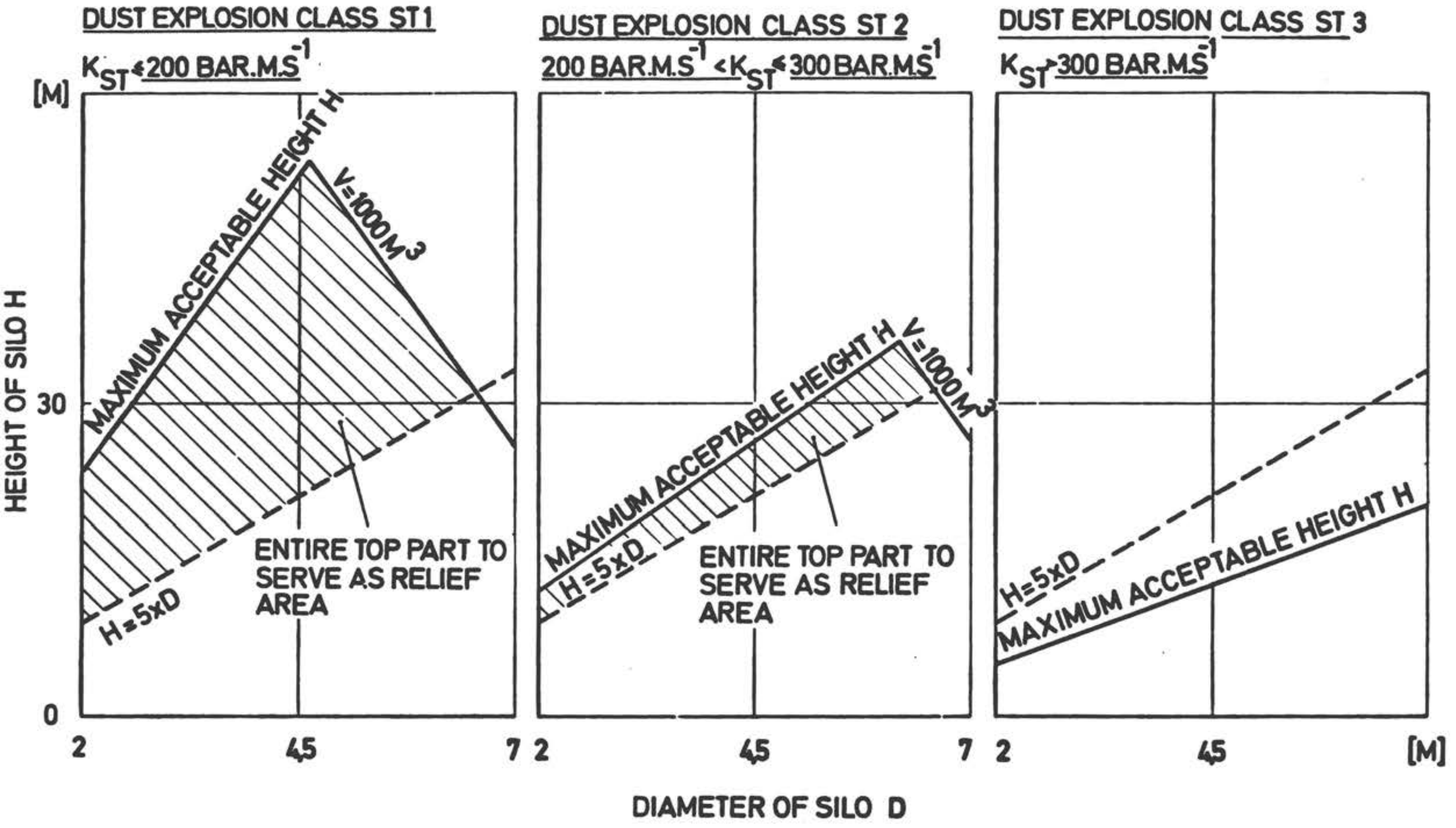
SICHERHEITSDIENST

STÄUBE: Einfluss von Ausblaseleitungen auf den reduzierten Explosionsdruck im zu schützenden Behälter

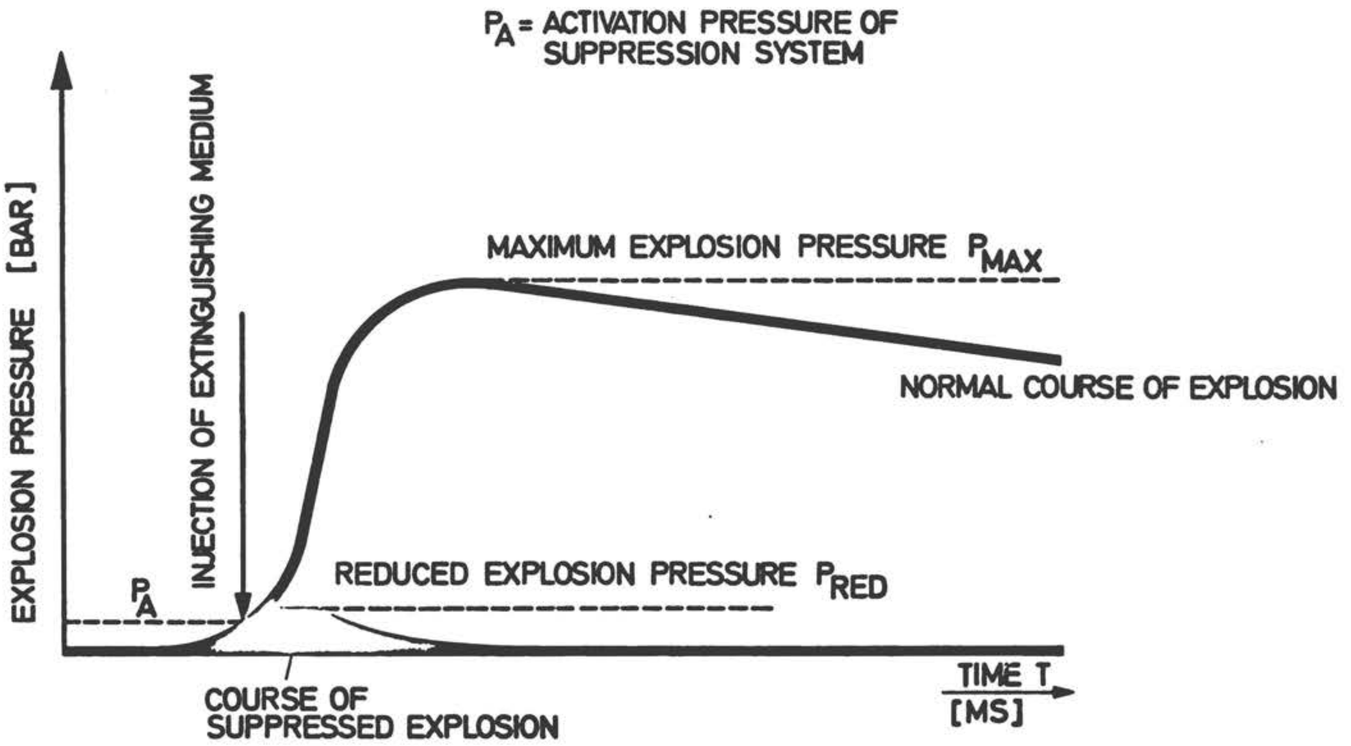
Bt 1/76



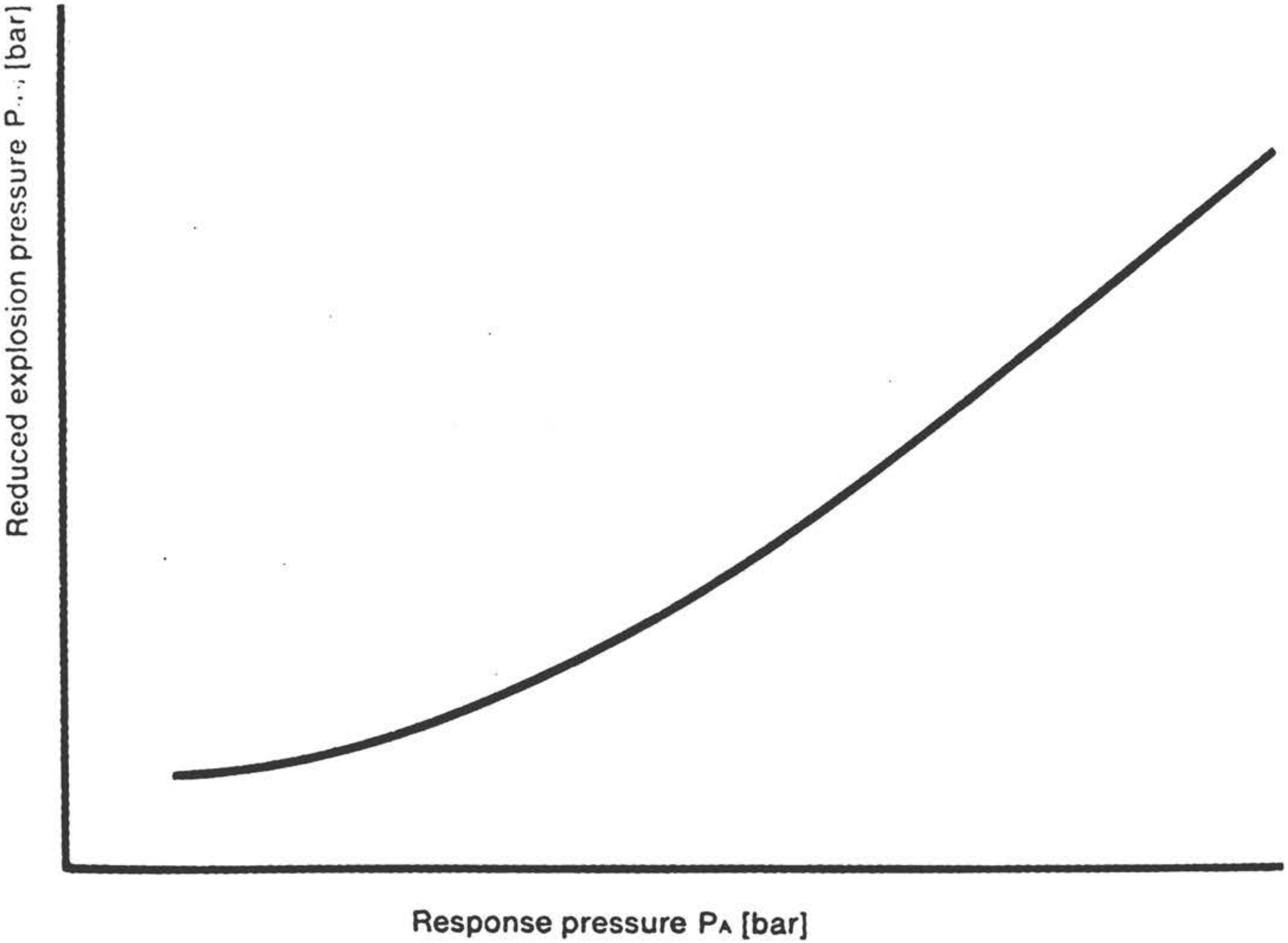
CIBA-GEIGY SICHERHEITSDIENST	Einfluss der Druckfestigkeit von Silos auf die Bauhöhe	Bt 312/75



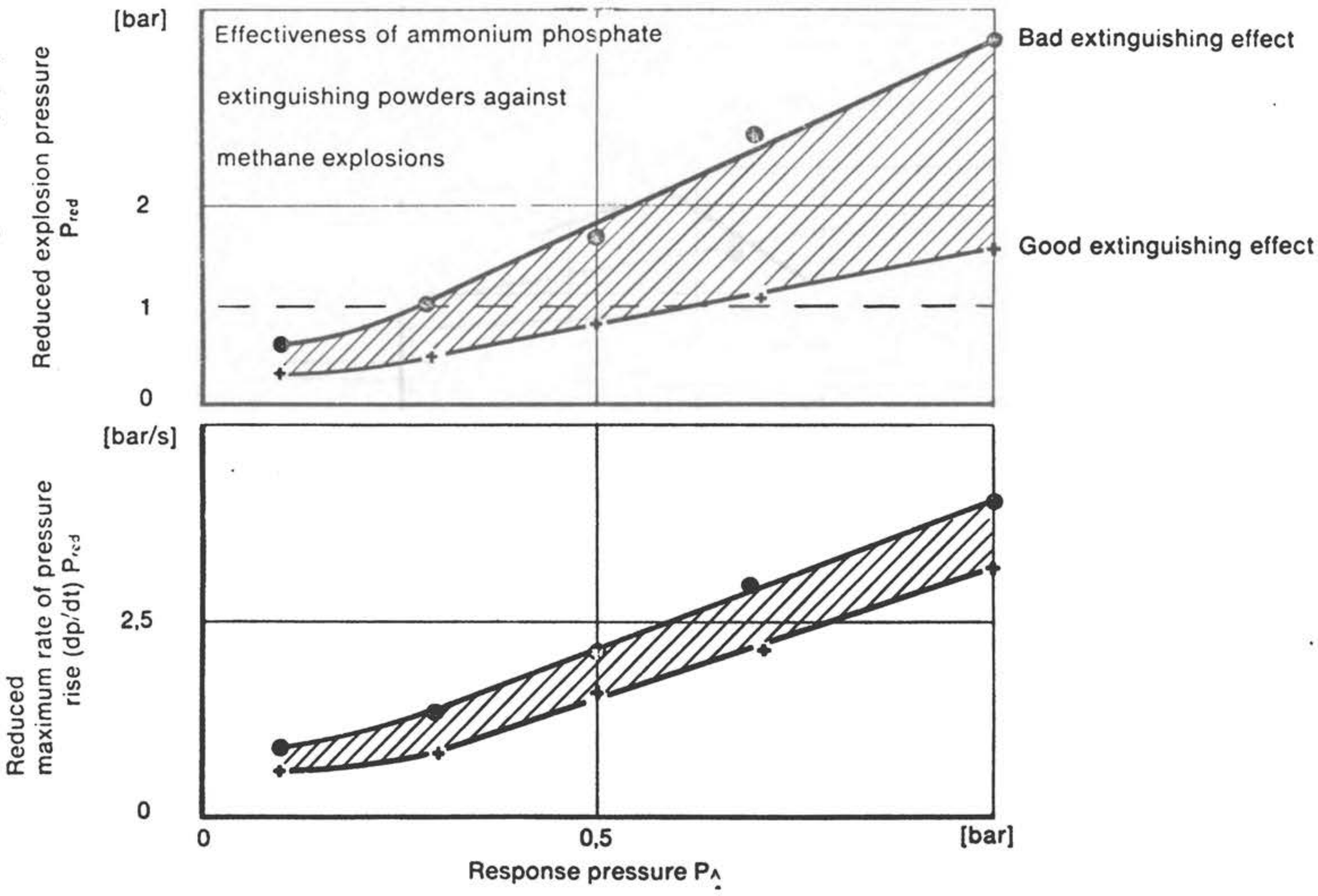
CIBA-GEIGY SICHERHEITSDIENST	Stäube: Zulässige Bauhöhe H von Silos $P_{stat} = 0{,}1$ bar $P_{red} = 0{,}4$ bar	Bt 301/75

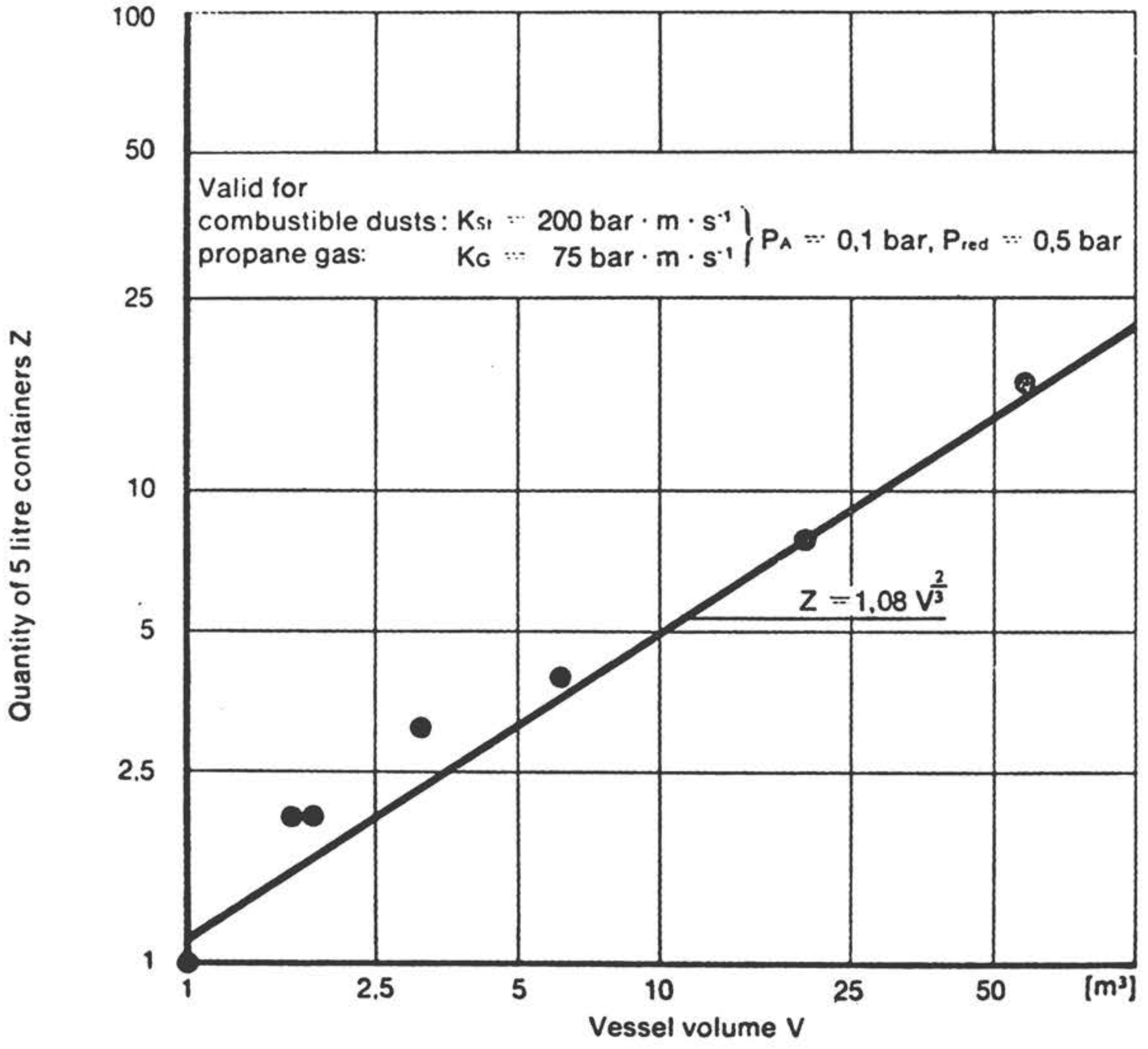


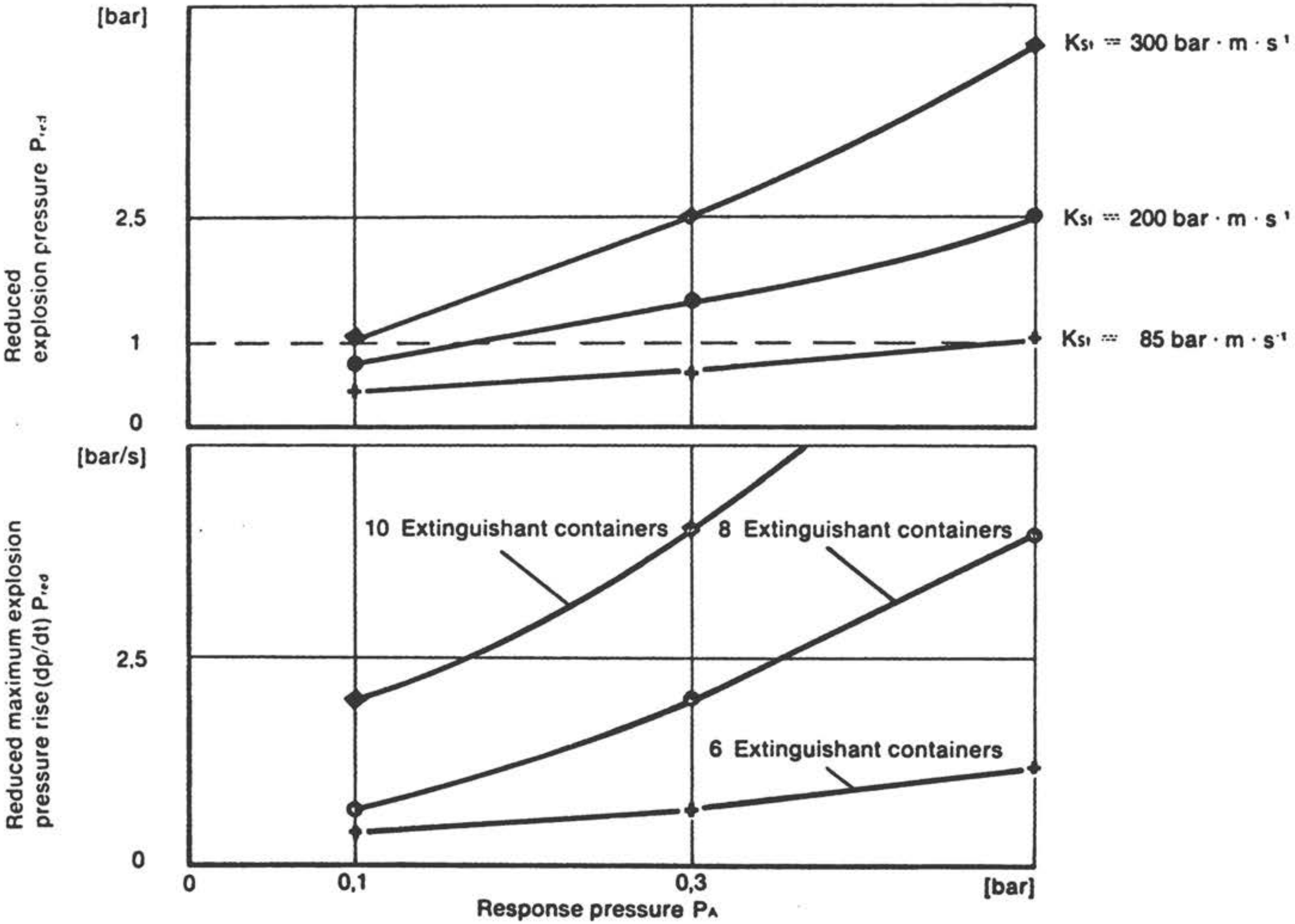
CIBA - GEIGY SICHERHEITSDIENST	PRESSURE/TIME CURVES OF AN UNSUPPRESSED AND A SUPPRESSED DUST EXPLOSION	**Bt 208/77**

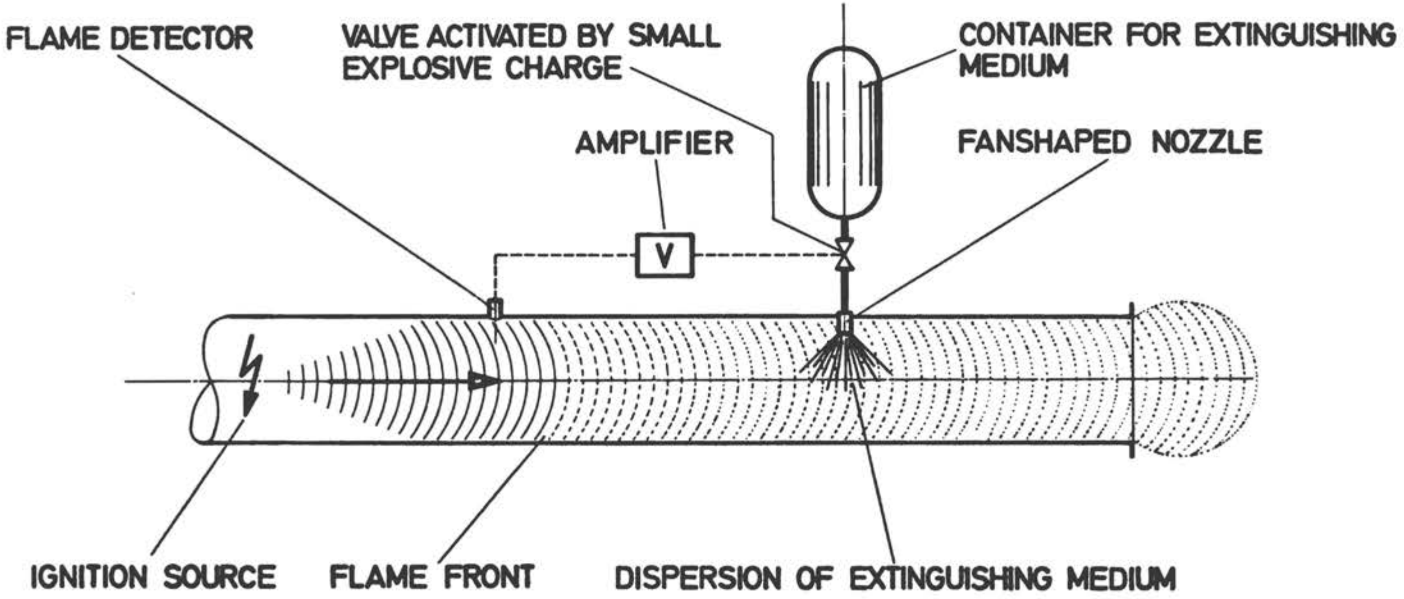


Reduced explosion pressure P[illegible] [bar]
Response pressure P_A [bar]


Effectiveness of ammonium phosphate
extinguishing powders against
methane explosions
[bar]
Reduced explosion pressure P_{red}
2
1
0
Bad extinguishing effect
Good extinguishing effect
[bar/s]
Reduced maximum rate of pressure rise (dp/dt) P_{red}
2,5
0
0
0,5
[bar]
Response pressure P_A


Valid for
combustible dusts: K_{St} = 200 bar · m · s^{-1}
propane gas: K_G = 75 bar · m · s^{-1}
P_A = 0,1 bar, P_{red} = 0,5 bar
$Z = 1{,}08\,V^{\frac{2}{3}}$
Quantity of 5 litre containers Z
100
50
25
10
5
2,5
1
1
2,5
5
10
25
50
[m³]
Vessel volume V

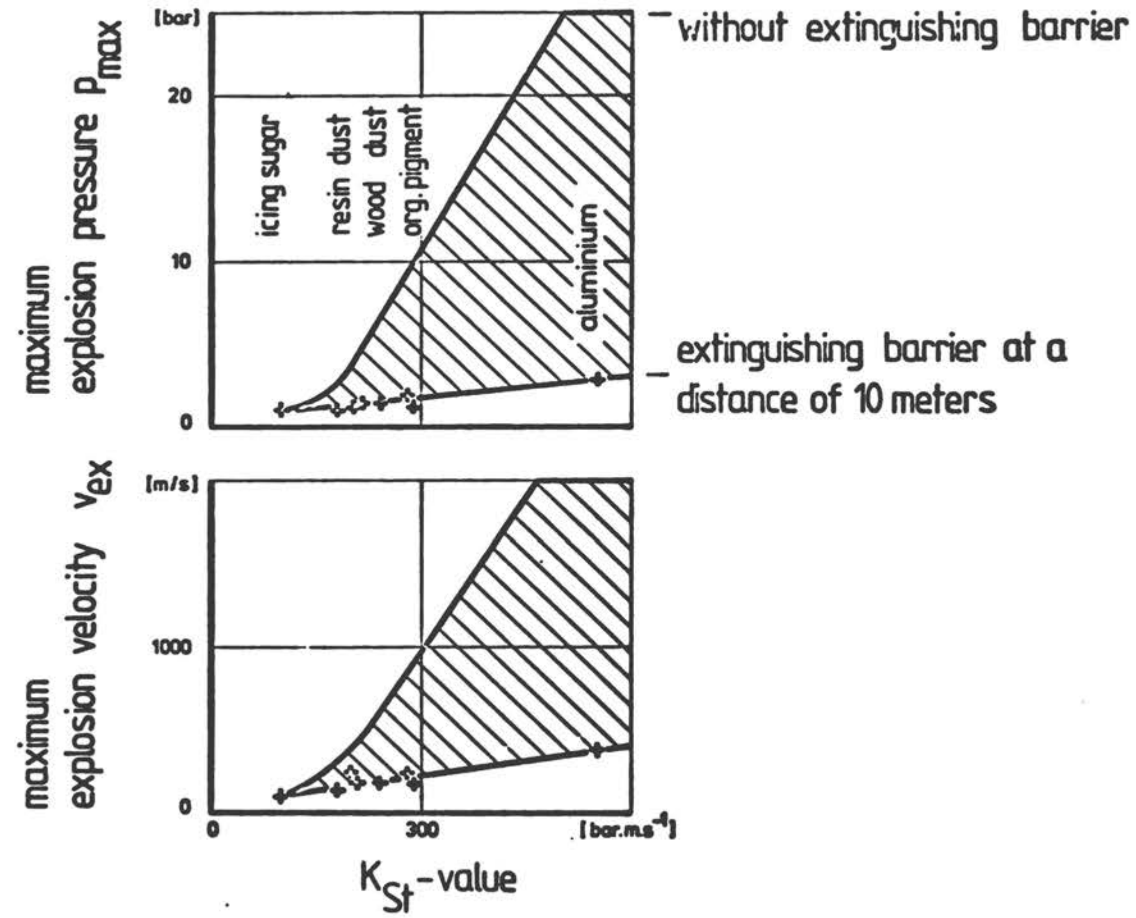

[bar]
Reduced explosion pressure P_{red}
2,5
1
0
K_{St} = 300 bar · m · s⁻¹
K_{St} = 200 bar · m · s⁻¹
K_{St} = 85 bar · m · s⁻¹
[bar/s]
Reduced maximum explosion pressure rise (dp/dt) P_{red}
2,5
0
10 Extinguishant containers
8 Extinguishant containers
6 Extinguishant containers
0
0,1
0,3
[bar]
Response pressure P_A



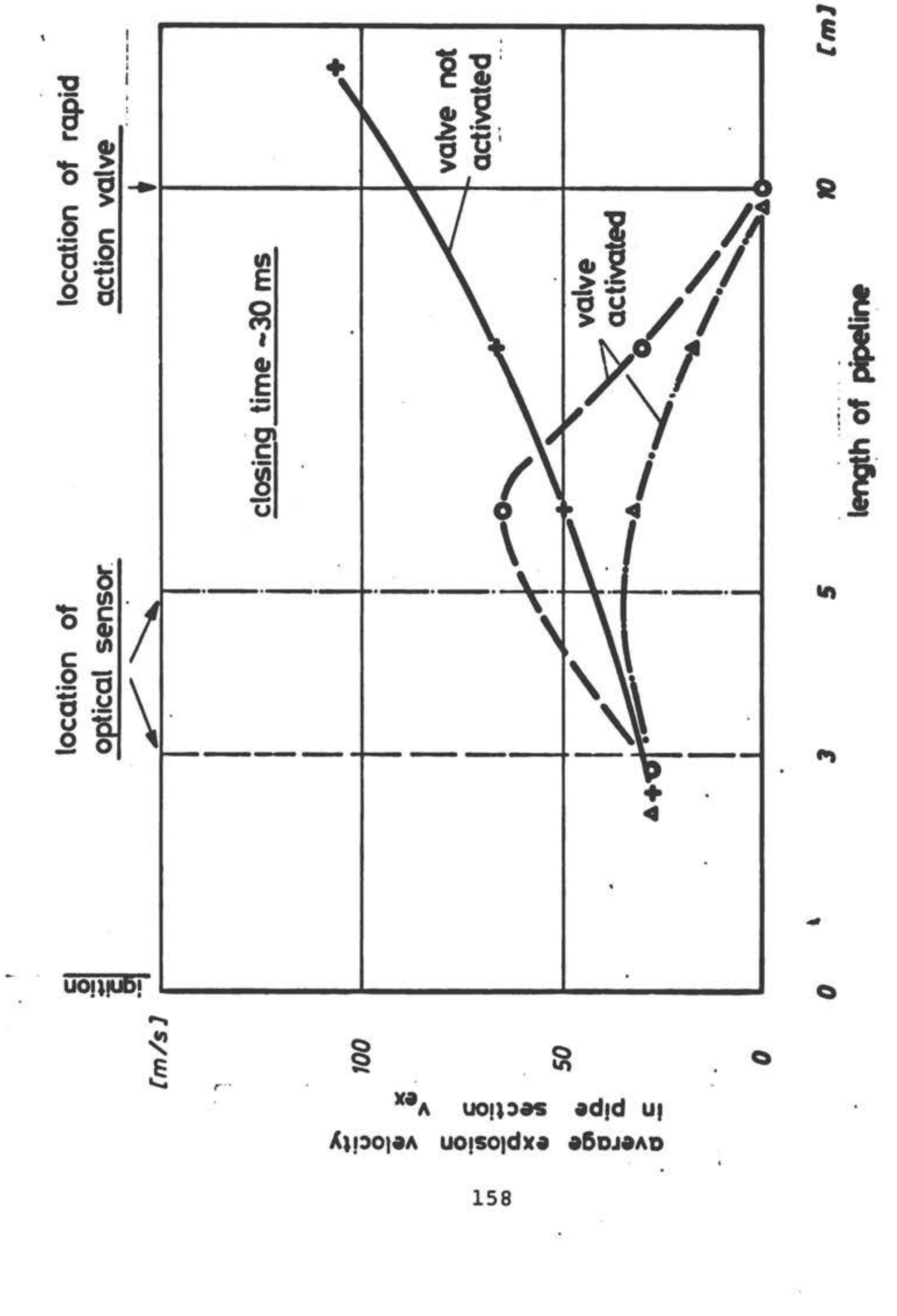
CIBA - GEIGY
SICHERHEITSDIENST

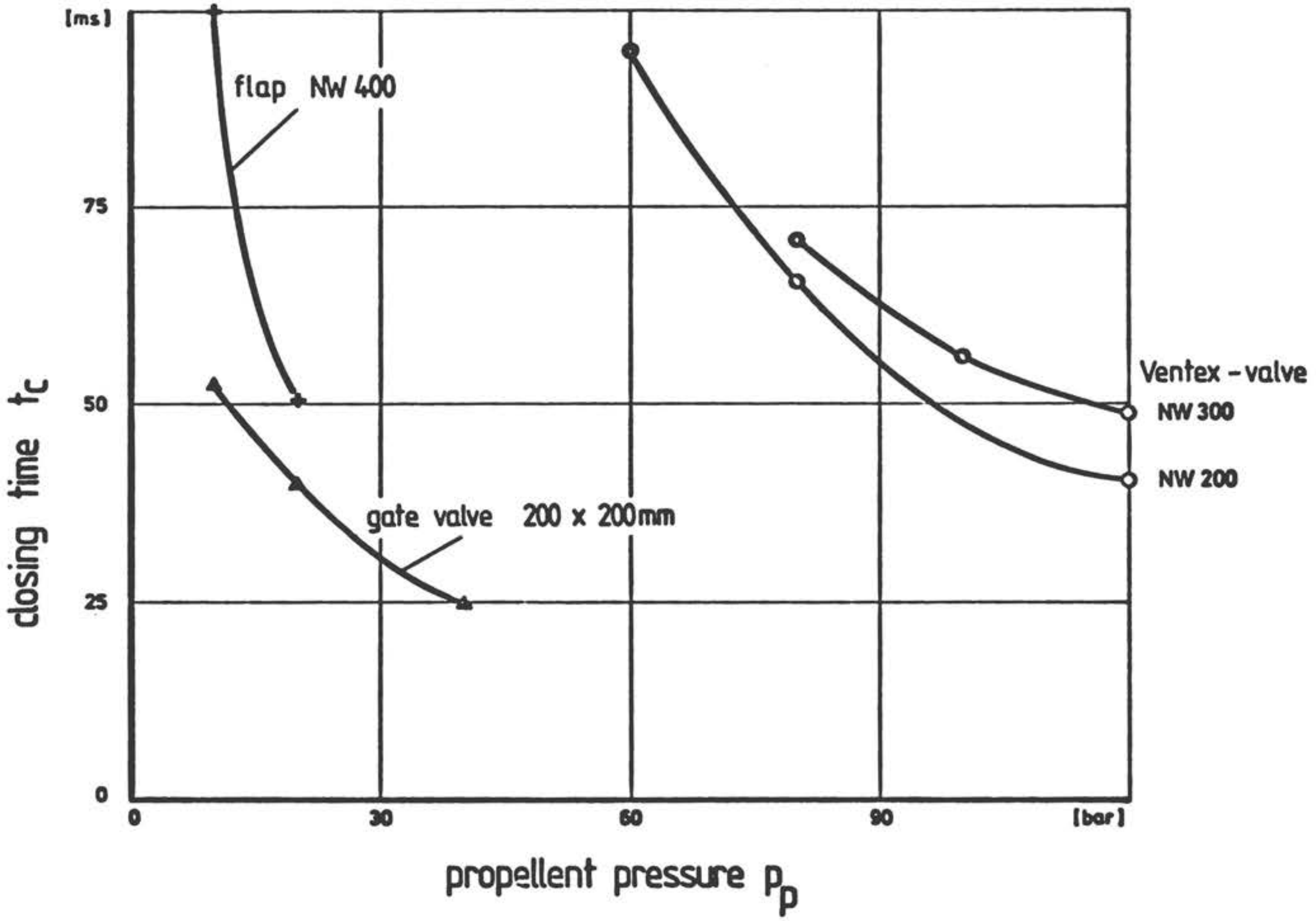
AUTOMATIC LINE EXTINGUISHER (SCHEMATIC)

Bt 254/73



CIBA – GEIGY **SICHERHEITSDIENST**	**Rohrleitung NW 400, l = 20 m** **Wirksamkeit von Löschmittel-Sperren**	**Bt 4/77**


location of rapid action valve
location of optical sensor
ignition
closing time ~30 ms
valve not activated
valve activated
length of pipeline
[m]
0
3
5
10
[m/s]
100
50
0
average explosion velocity in pipe section v_{ex}



CIBA-GEIGY
SICHERHEITSDIENST

Schließzeiten von Schnellschluß-einrichtungen

Bt 7/77

ELECTROSTATIC CHARGING OF DUST AND THE CONTROL OF INDUSTRIAL DUST, FUME AND SMOKE BY CHARGED WATER FOG

by

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Federal agencies, corporations and industrial organizations included the American Foundrymen's Society, the Ransburg Corporation, the ARO Corporation, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the National Institute of Occupational Safety and Health.

ABSTRACT

We have investigated the charging behavior of a variety of industrial dusts as they are dispersed into the air. In general, the charge is negative (with some exceptions); however, in every case we have found it possible to suppress the dust and induce rapid agglomeration by exposure to oppositely charged water fog.

Laboratory and industrial test data for the water fogging system is available and applications to control of grain dust charging will be discussed.

INTRODUCTION

Fugitive dust, fume and smoke are of concern to a wide variety of industries. In many situations the sources of pollution are diverse, moveable or unsuitable for control by conventional hoods and fans. In many cases the most serious problem is the respirable dust fraction, because it can enter the human lung. The respirable dusts (below 10 microns) are also those most prone to drift about the plant and become a hazard to the community at large. Under these circumstances it is imperative that respirable dusts be induced to agglomerate and fall out as close to the point of generation as possible.

APPLICATION OF CHARGED FOG TO POLLUTION CONTROL

Many attempts have been made to agglomerate respirable dusts by means of water sprays. In most cases there has been little success because of poor dust-water droplet contact. A mechanism beyond mere mechanical impact is required if water sprays are to be effective in dust control. We have suggested that dust-water drop contact can be enhanced by charging the water drops to a polarity opposite to that of the dust. The resultant electrostatic forces are very effective in promoting dust-droplet contact. It should be noted that quantity of water involved is usually very small; typical fog gun water flows are some 3.8 l per hour. In many cases satisfactory results have been achieved with flows of 1.2 l per hour. This has allowed us to work in areas where excessive water would damage products or induce rusting. Typical changes in the ambient relative humidity, when the fog gun is operating, are about 3%.

The charged fog system does require that the dust be charged as it is dispersed into the air. We have investigated the electrostatic characteristics of some forty different industrial dusts [4, 5, 6, 7]. In every case the respirable fraction was charged to a greater or lesser degree. The dispersion apparatus dust tunnel and the measurement system are shown in Figures 1, 2, and 3. Typical results for several industrial dusts are shown in Figures 4, 5, and 6. Notice in Figure 4 that the one micron, respirable, fraction of silica is negatively charged. We have suggested that this is connected with its potential for induction of silicosis [12]. In the discussion below we shall demonstrate that this charging effect can be exploited to reduce the respirable silica in an industrial environment.

The control technique involves recognizing that the respirable dust is charged and exposing it to a flow of oppositely charged water fog. The electrostatic forces induce rapid water-dust contact, the dust is wetted and the agglomeration fallout process proceeds rapidly. This use of appropriately charged fog is advantageous for two reasons. First is the actual reduction of the dust charge itself, since the dust is contacted by oppositely charged water fog. This reduces the hazard of electrostatic discharges that might ignite flammable materials. The second advantage depends upon the well-known fact that as dust is wetted its inherent tendency to triboelectric charging is greatly reduced. Test results, to be discussed below, suggest that the fine (50 micrometer diameter) fog is easily absorbed by most industrial dusts, and that the water is not desorbed even at high (250 C) temperatures. This provides an added safety factor with flammable particulates.

As an example of the fogging system in action we show in Figure 7 an experimental system for the study of dust "boil-up" during dumping. Typical photographs showing the dust boil-up, with and without charged fog, are shown in Figures 8 and 9. The fog gun is a commercial model, Fogger I, manufactured by the Ransburg Corporation of Indianapolis, Indiana.*

Other tests of the charged fog system have been run in the dust tunnel shown in Figure 2. Typical results with foundry sweepings, bauxite and grain dust are shown in Figures 10, 11 and 12. Similar data have been obtained with some forty other materials; the data has been reported in our EPA Reports [4, 5, 6, 7].

One application of particular interest concerns the control of coke oven fume and benzine solubles from a simulated coke oven preparation. The data is shown in Figures 13 and 14. In both cases there was a significant reduction in pollutant level when charged fog was used.

Another application involves the control of fibrous materials, i.e., lead, zinc and arsenic are known to be sources of industrial injury. Welding is a problem in this area because of the metallic fume and the smoke from the flux coated rod. This situation was investigated with the apparatus shown in Figure 17; the results are shown in Figure 18. There was a substantial reduction in metallic fume/smoke, and the welder commented that there was no apparent change in welding characteristics or results. We feel that this application is a significant one, in that it demonstrates how charged fog can be used for fume control without the need for bulky hoods that may interfere with the operator. We might note that the four-inch pipe shown in Figure 17 was <u>only</u> required to draw off fumes for the test; in an actual welding operation there would be no need for this unit.

Another problem with lead/zinc fumes involves melting and fluxing operations in smelters. To simulate this situation, on a small scale, a four-pound thermostatically controlled lead pot was used to produce the fume. The fume was drawn into a duct by a Transvector and exposed to a flow of charged water fog. The objective here was twofold. Control methods for metallic fume have been hampered by the clogging and damage that occurs when conventional fan-driven hoods are used. The Transvector (Vortec Corporation,

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*Reference to any commercial apparatus in this report does not represent an endorsement of such apparatus by EPA, the Federal Government or the University of Arizona. This data is presented FOR READER INFORMATION ONLY.

Cincinnati, Ohio 45229) operates on the coanda flow principle, with no moving parts. We hoped to demonstrate that this system can operate, in a duct handling metallic fume, without clogging. The addition of charged fog would be expected to induce agglomeration. Once this had occurred, the particle would be non-respirable and could be expected to fall-out quite rapidly.

The experimental studies with this system are still under way, but the preliminary data is encouraging. We hope to apply the same type of system to the fugitive dust/smoke problem that exists in smelters handling copper or zinc ore. The proposed system is shown in Figure 19. The Transvector would be significantly more resistant to corrosion than the usual fan motors, and the quantity of charged fog would be large enough to induce the SO_2 generated during smelting to absorb on the dust thereby inducing agglomeration and fall-out. We would not expect any liquid acid or water/acid solution to be present.

HIGH TEMPERATURE STUDIES

One of the questions raised about the charged fog dust control system is the application in high temperature environments where some of the fog might be lost to evaporation. In previous reports [4] we suggested that most of the fog would be captured by dust and, therefore, be available for agglomeration, even at high temperatures. At that time there was only a limited amount of data to support this idea. More recent results were obtained with the system shown in Figure 20. In this series of tests we held the initial level of dust (copper company fly ash) and SO_2 constant and observed the effect of charged fog on the reduction of SO_2 and fly ash. Typical results, over a range of temperatures, are shown in Figures 21 and 22. It is clear that the charged fog is effective in reducing the SO_2 and the dust level. The effect of the charged fog, on the dust, does not vary appreciably with temperature, but the SO_2 reduction is a maximum at about 250 C. This was observed consistently and we suggest that below 250 C most of the SO_2 has not converted to SO_3 and is relatively insoluble in the fog. At 250 C the conversion is almost complete and the effect is large, while at higher temperatures the SO_3 becomes less soluble in the fog and the effect falls off. At present we have no apparatus for measurement of SO_3 versus SO_2, so this is mere speculation. We hope to continue these tests and obtain apparatus that will allow continuous monitoring of the SO_2 and SO_3 concentrations.

One question of interest here is the actual "fate" of the SO_2 or SO_3 after fogging. In earlier reports [4] we suggested that the SO_2/SO_3-water mixture is absorbed by the dust and assists in the process of dust agglomeration. If this is true, it provides a method for suppressing both dust and SO_2 at the same time. Further tests of this hypothesis will involve the larger test system discussed in the next section.

LARGER TEST SYSTEMS AND APPLICATION OF CHARGED FOG TO DUST CYCLONES

The present test system, Figure 20, is quite small and it is difficult to separate "wall effects" from processes that might go on in the gas phase. We have received funding from the Anaconda Copper Corporation to build a fly ash/SO_2 test facility on the University of Arizona campus. A schematic drawing of the new facility is shown in Figure 23. This unit is essentially complete, except for the dust/SO_2 scrubber which is still on order. In the interim we are cooperating with the cotton gin operators in an attempt to improve the dust cyclones normally used at gin facilities. These units are of the "dry" type and are relatively ineffective for respirable particulates. Attempts to use "wet" cyclones have failed because of clogging and the ginning industry is faced with a serious pollution problem.

We have suggested that the application of a small quantity of properly charged fog ahead of the cyclone would induce agglomeration of the respirable material, and thereby improve the cyclone operation. If this can be done for cotton trash, the same technique can probably be extended to other materials, i.e., grain dust. Cyclones are frequently used for cleaning air in grain elevators, and again their performance for respirable particulates is poor.

The cyclone test system is shown schematically in Figure 24 and preliminary data indicates that the charged fog does improve the cyclone efficiency on cotton trash. Further tests with grain dust are in the planning stage.

DEVELOPMENT OF LARGER FOG GUNS

One barrier to the wider use of charged fog is the limited size of the units commercially available. The commercial Fogger is shown in Figure 9; the limiting water flow rate of about 1 gallon per hour (3.78 l/Hr) is only sufficient for "small dust sources" and we recognize the need to develop larger systems.

The problem here is not simply generating more fog. The fog must be charged, and this is difficult to do with electrostatic induction when the fog flow is very heavy. In a heavy fog flow only the outer layer of fog, that nearest the induction charging ring will be charged. Another problem with the induction ring system is the stored electrical energy that might be released in a spark, to ignite flammable dust or gases

For this reason we have looked at two systems for direct charging of the fog via a corona discharge. In one case we found it practical to charge such flows directly by holding the nozzle at a high voltage. This does present the problem of electrical leakage down the water supply line, but we have found it possible to eliminate this leakage by the use of plastic tubing and injecting air bubbles into the water stream close to the nozzle. The bubbles provide a barrier to the flow of electricity without interfering with the operation of the fog nozzle.

Another system which follows the work of Splinter [11] makes use of a corona needle mounted at distance of 1 cm from the grounded nozzle. The needle is held at a high voltage (15 kV) to generate a corona discharge, the fog flows through the discharge and is charged by ion diffusion. This system has the advantages that the nozzle and associated water system is at ground potential and that the stored energy in the high voltage apparatus is quite small.

Another problem with large scale use of charged fog is the "projection" of the fog some distance, i.e., 25 feet (7.62 m). If fog droplets are thrown into still air they will travel some 3 feet (0.91 m) before being "stopped" by aerodynamic drag. The best way to extend this range is to provide a "sheath" of moving air around the fog. This moving air will carry the fog with it to the target. The large fog nozzles do provide some sheath air naturally, but we have found it practical to increase the effect with Transvectors; a drawing of the Transvector equipped fog generator is shown in Figure 25. A photograph of the unit in action is shown in Figure 26. Typical fog water flows with this unit are 11 to 15 gallons per hour (41.6 to 56.8 l/Hr) and charge collection tests have indicated that we are charging all of the fog rather than the outer shell, as would be the case with induction charging.

To demonstrate the effect of this dust control system on a "large" dust source we set up the dust generation system shown in Figure 27. Figure 28 shows the effect of the charged fog in reducing this pollution. The dust in this case was gypsum, which we have found to be a low cost material for these large scale tests. Typical numerical data with a system of this type is shown in Figure 29.

INDUSTRIAL TESTS

The available data from industry is limited to what we can obtain at local mines, smelters, cement plants, etc., and most of the results in 1977 were discussed in our earlier reports [4 , 5 , 6]. One example of a typical industrial application, that might well apply to many industries, involved the unloading of silica sand from a boxcar. The respirable dust and the free silica level were quite high, in this case, and the company felt that a serious problem existed. The boxcar was fitted with four fog guns, as shown in Figure 30; the guns were operated to generate a positively charged fog during unloading, and the dust levels were monitored by personnel samplers on the workmen. The data was reduced by company personnel and typical results are shown in Figure 31; notice that there was a significant reduction in respirable dust (86%) and in free silica. These results should be appreciated in the light of Figure 6, where it was shown that the 1 micron fraction of the silica sample was highly charged to a negative polarity.

More recent industrial test data, taken at the Tucson facility of the Gates Learjet Company, involved dust control on a belt sander. The physical layout is shown in Figure 32. The irregular nature of the sander operation and the movement of workmen, lift trucks, etc., in the area precluded numerical measurements of the dust level. It was decided to look for "visual results" with the charged fog. Typical before and after photographs are shown in the attached Figure 33; it was very apparent that the charged fog reduced visible dust generated by the sander, and Company management has made arrangements for installation of one or more fog guns.

Other industrial results, at a local sandblasting operation, are shown in Figures 34 and 35. Here, again, the irregular nature of the operation and the ambient winds precluded the use of conventional dust samplers. The fact that the man running the sandblaster was protected by a White Cap System and the need to keep the fog off sandblasted surfaces made it impractical to use personnel samplers. We chose to photograph the operation, with and without the fog, as shown in Figures 21 and 22. There was a significant reduction in visible dust, and the company involved is rebuilding their sandblast booth to accommodate a fog gun.

Arrangements have been made for a number of other industrial tests on a copper smelter, a front loader and a grain dumping operation. The results will be discussed in subsequent reports.

MECHANISMS OF DUST CHARGING

The fact that dust charges when dispersed into the air has been known for some hundreds of years, and a review of the experiments and theories up to 1967 was given by Loeb [10] and Harper [3]. In the case of dissimilar materials, i.e., sulfur and red lead, the charging may be explained on the basis of differences in Fermi level and the resultant work function. It is more difficult to explain the observations of dust charging when only a single material, i.e., SiO_2, is present.

Dispersion tests on ultra pure silica were reported by Loeb [10]. and it was indicated that charging was essentially uniform in that there were as many negative as positive particles at every size range. These results have been used by many authors to claim that a dust cloud will have an effective zero change and that the effects of charged water fog would be quite limited. A more careful study of the Loeb work indicates that when the silica was even slightly contaminated by metal (having been blown from a platinum cup) there was a predominance of negatively charged particles at the 2 to 8 micrometer diameters. This suggests that positively charged fog will be effective in the induction of agglomeration and fall-out. The data reported in references 4 through 7 indicates that positively charged fog is, generally, most effective in the suppression of industrial dusts.

The above, while interesting, does not help to explain the mechanism(s) involved and here we lean toward two theories, primarily that of Gallo and Lama [2]. They suggest that the effective work function of a material is a function of the particle size, with an increasing work function as the particle size decreases. This would mean that the smaller particles have a predominately negative charge, while the larger particles would tend to be positive. Our data [4-7] is in general agreement with this idea, although there are some exceptions which will be discussed below.

The other theory of dust charging is that of Latham [8] based on his investigations of snowflake electrostatics. He suggests that as the snowflakes slide over one another a temperature gradient is developed due to frictional heating. The larger snowflakes, having more thermal mass, are heated to a lesser degree than the smaller entities. This induces a net flow of sodium ions from the small flakes to the larger ones, and as a result the small flakes are negative and the larger positive. He supports this theory with calculations and measurements of blowing snow and suggests that the same mechanism might apply to sand and dust. This idea is attractive but at the present time we know of no measurements or calculations of the frictional heating as sand or dust particles slide over one another. Experimental studies in this area will be part of our next year's effort.

The sodium migration idea has other aspects which may help to explain the puzzling cases where all or part of the respirable dust fraction is charged positively, i.e., Figure 8 of reference [4]. We suggest the sodium is an almost ubiquitous contaminant in almost every industrial material. It is also the species having the highest speed of ion migration non-crystalline solids [1]. If the material is heated, the sodium will diffuse to the surface and be trapped in surface defects, small cracks, etc., thereby producing a dust having a positive surface charge. Surface segregation of trace elements has been observed on coal fly ash in agreement with above hypothesis [9].

We have begun some experiments designed to demonstrate the sodium migration effect and its influence on the surface charge of dust particulates. For this study a sample of commercial powdered quartz, provided by the International Minerals and Chemical Corporation of Libertyville, Illinois 60048, was ground with mortar and pestle and then vacuumed into the modified Anderson 2000 sampler and Trek voltmeter system discussed in our first report [4]. The charge was measured as a voltage and is shown in the open bars on the histogram of Figure 36. All of the dust was negatively charged, but the larger particulates had the highest level of charge.

The dust was then heated to 250 C for twenty-four hours and the grinding, sampling process was repeated. The data is shown in the cross-hatched bars of Figure 36. In every case there was a significant drop in the level of negative charge, in agreement with the sodium migration theory. No positive charging was observed, but this may have been due to the low level of sodium in the relatively pure silica. We plan to repeat this experiment with pure quartz, desert sand and other particulates at a series of increasing temperatures, to see if the sodium diffusion effect can be confirmed.

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LIST OF ILLUSTRATIONS

FIGURE 1 Dust Generator and Sampling System.

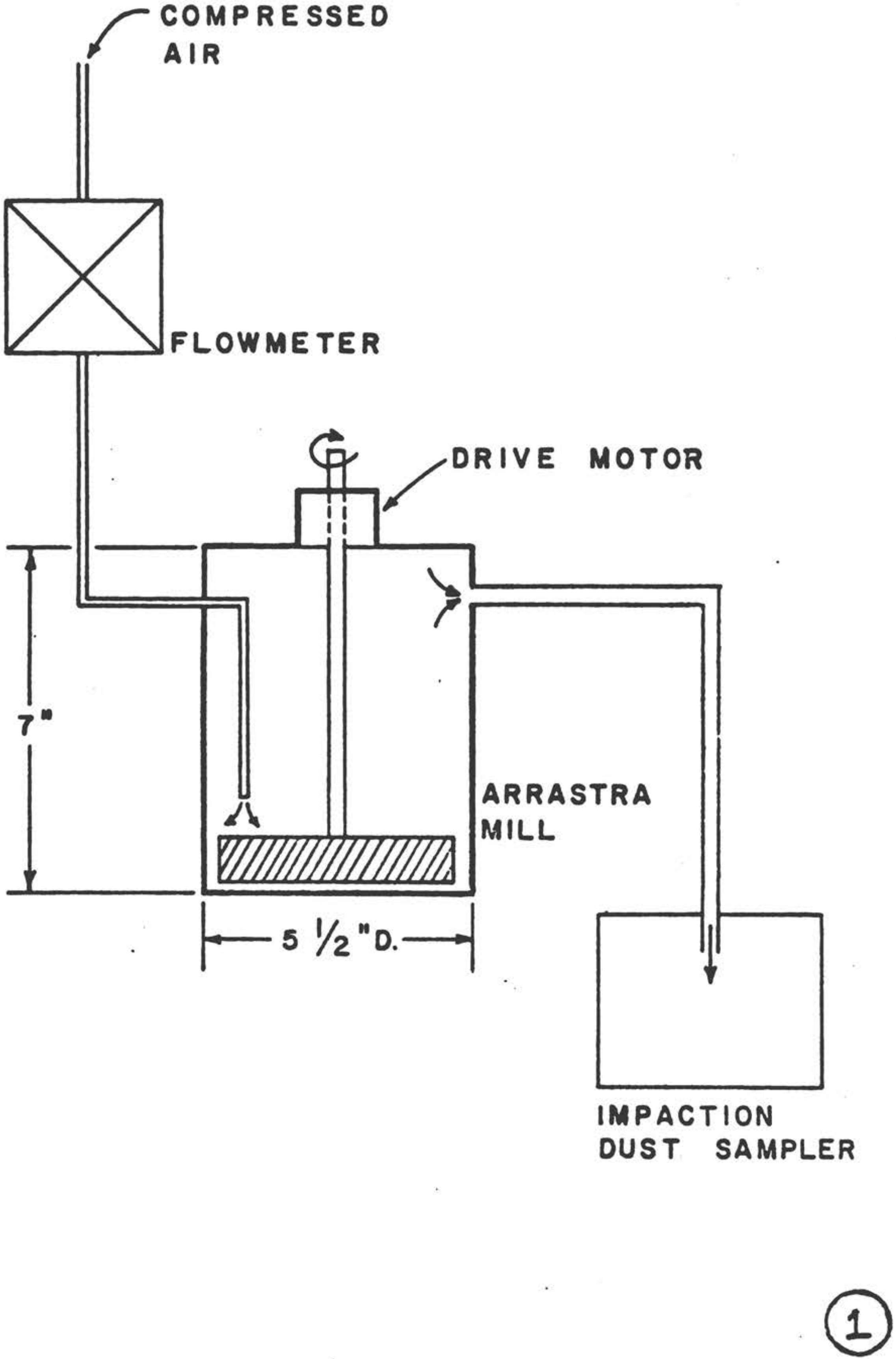

FIGURE 2 Experimental Dust Tunnel.

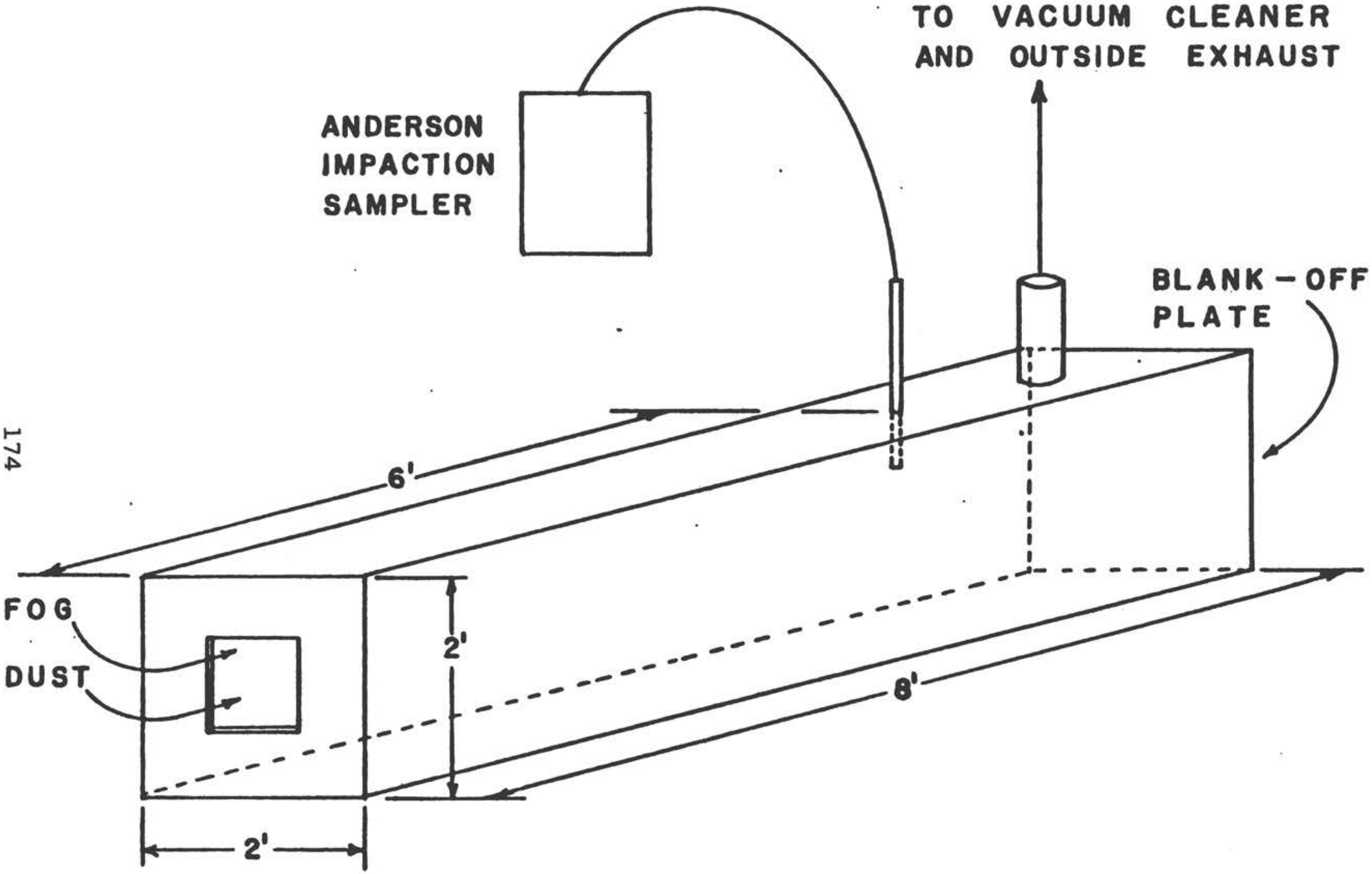

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FIGURE 3 Modified Impaction Sampler.

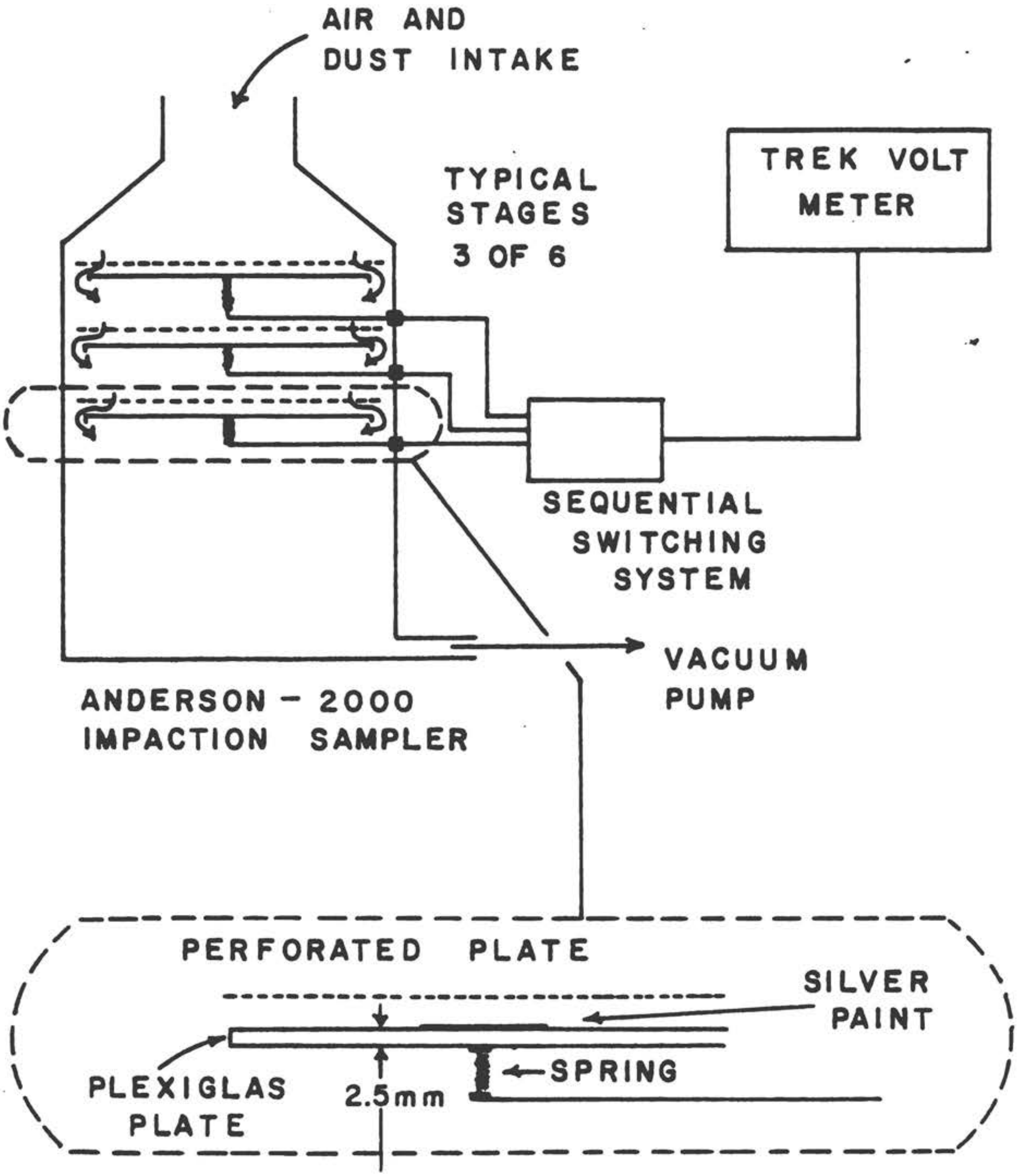

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FIGURE 4 Charge versus Particle Size (slate).

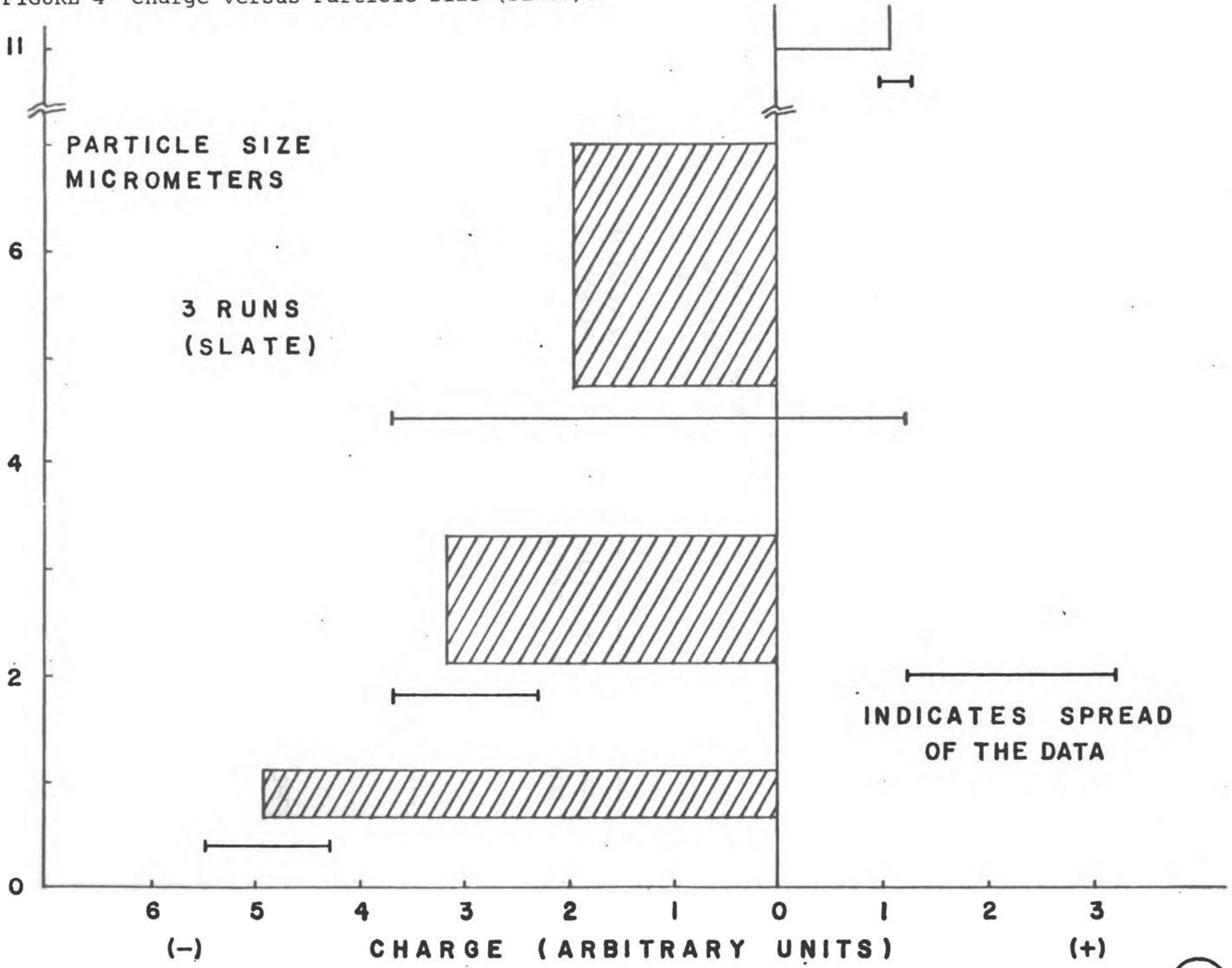

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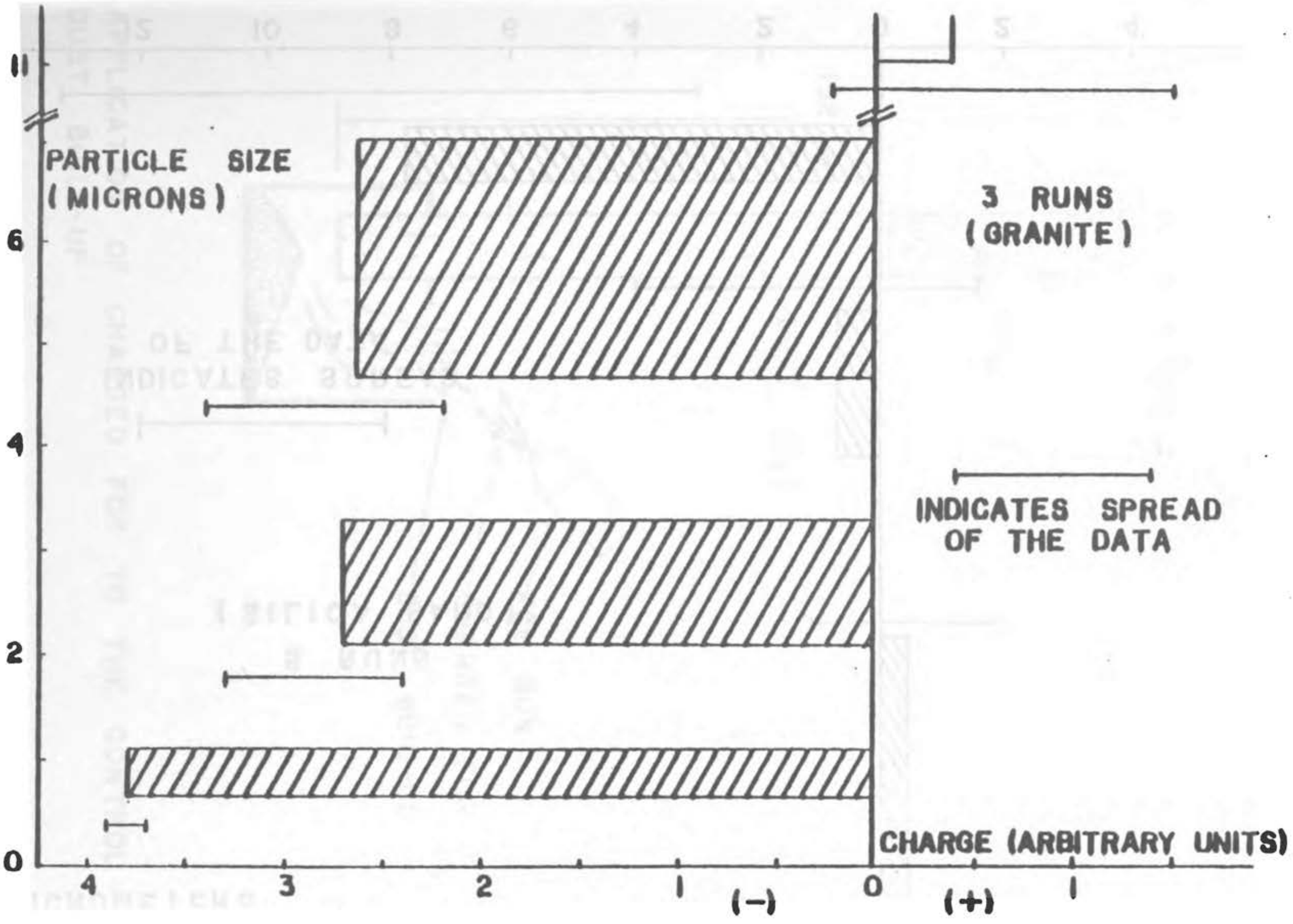
FIGURE 5 Charge versus Particle Size (granite).



Charge versus particle size, granite.

⑤

FIGURE 6 Charge versus Particle Size (silica sand).

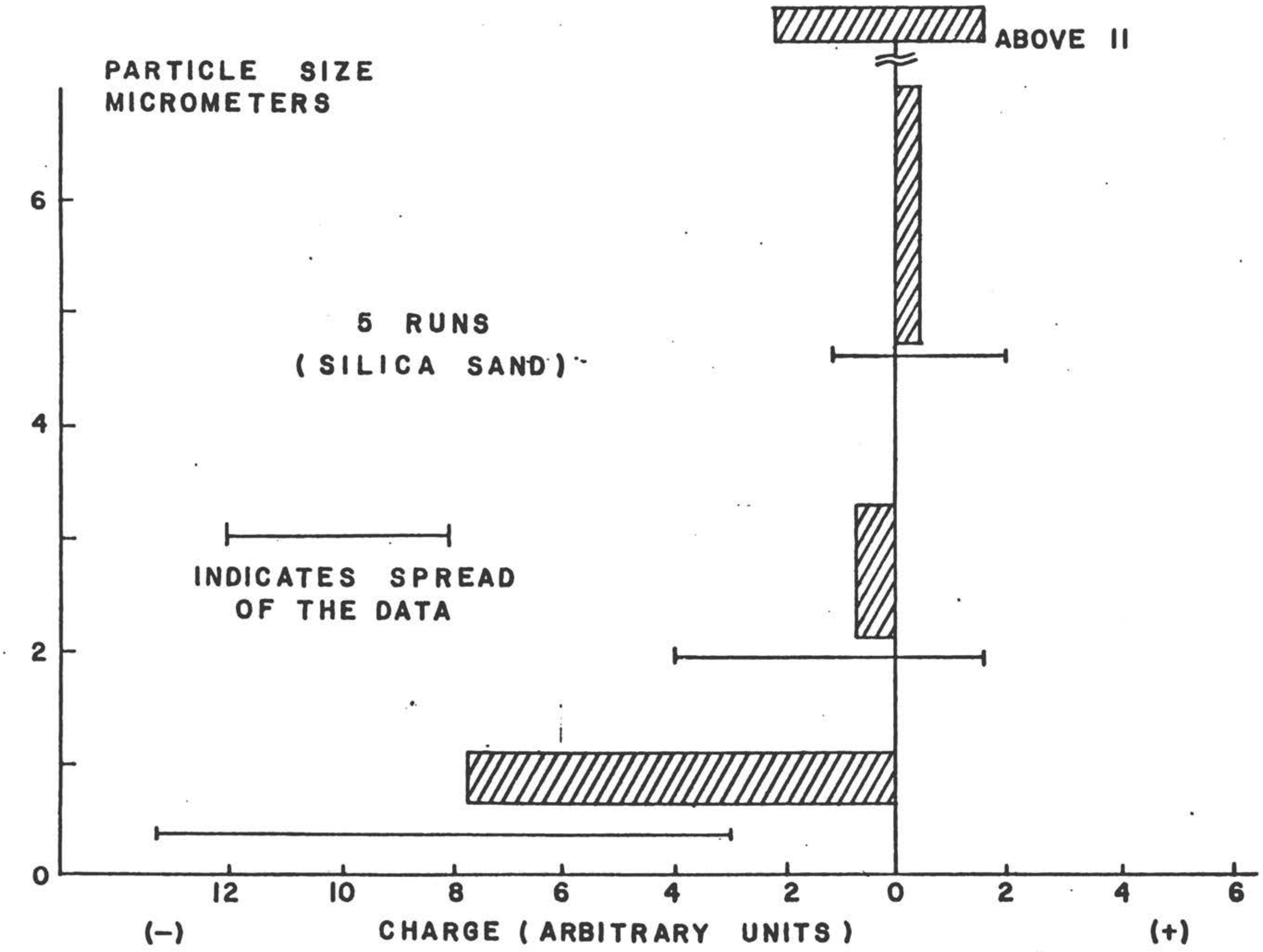


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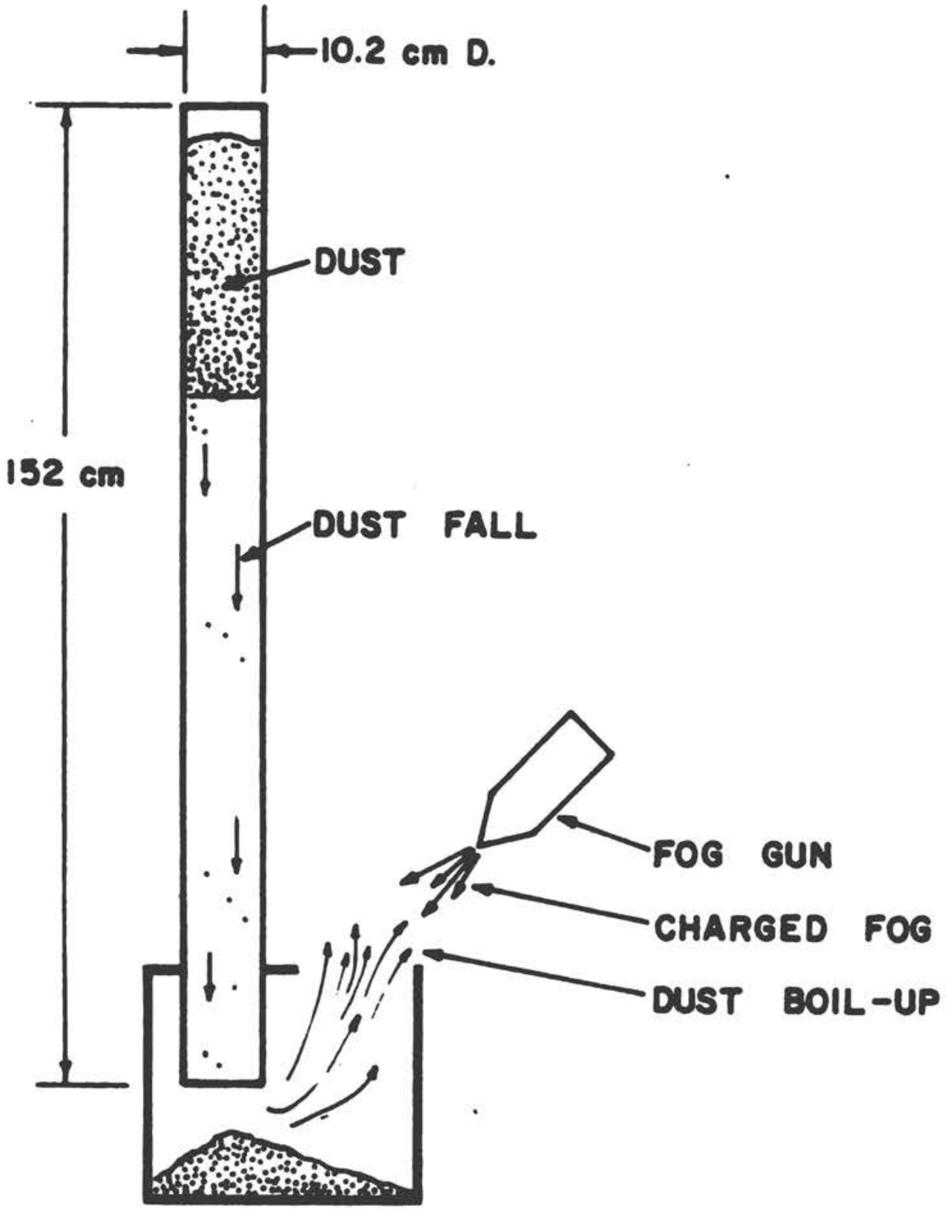
FIGURE 7 Application of Charged Fog to the Control of Dust Boil-up.



APPLICATION OF CHARGED FOG TO THE CONTROL OF DUST BOIL-UP

FIGURE 8 Dust Boil-up with Charged Fog "Off."

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FIGURE 9 Dust Boil-up with Charged Fog "On."

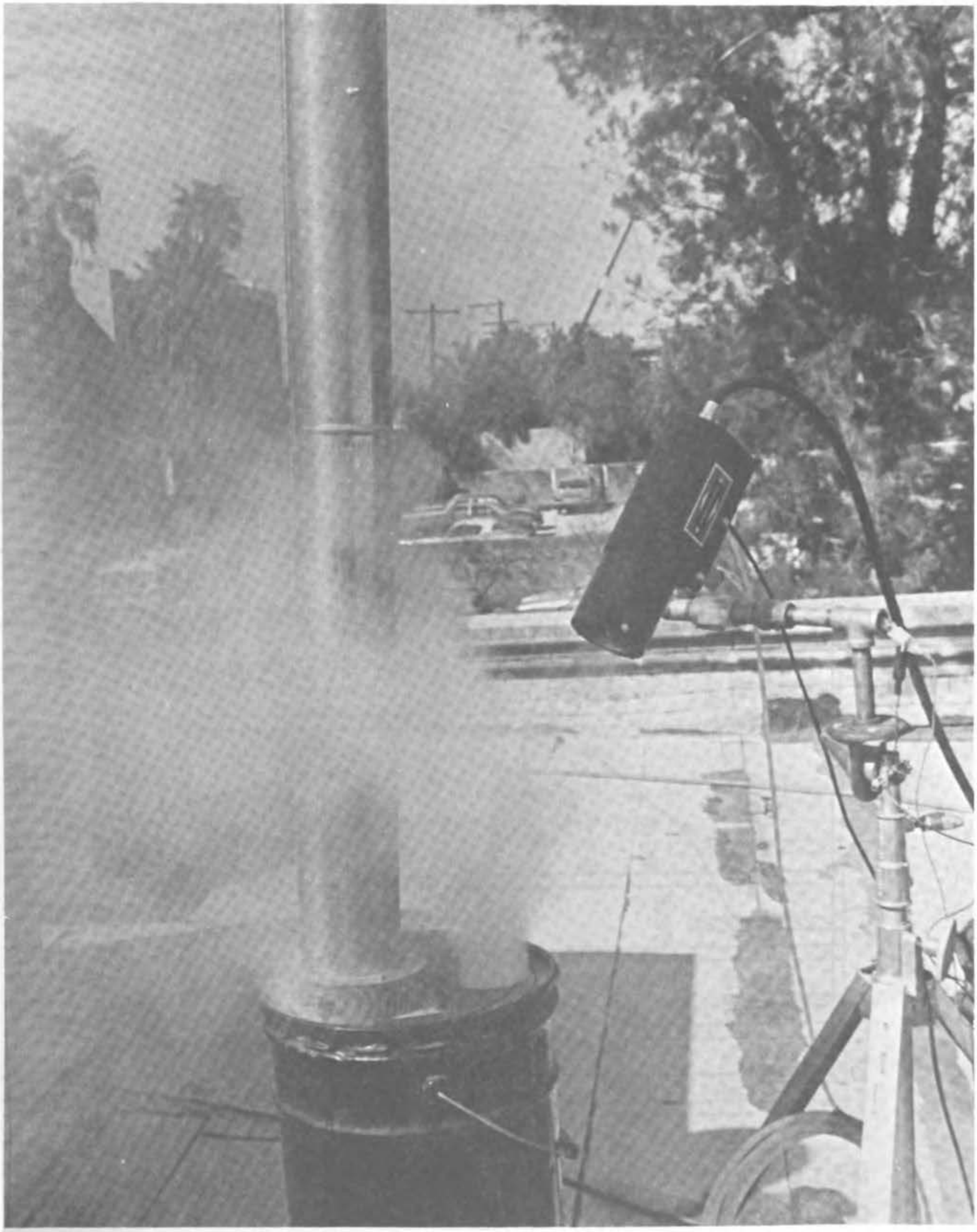

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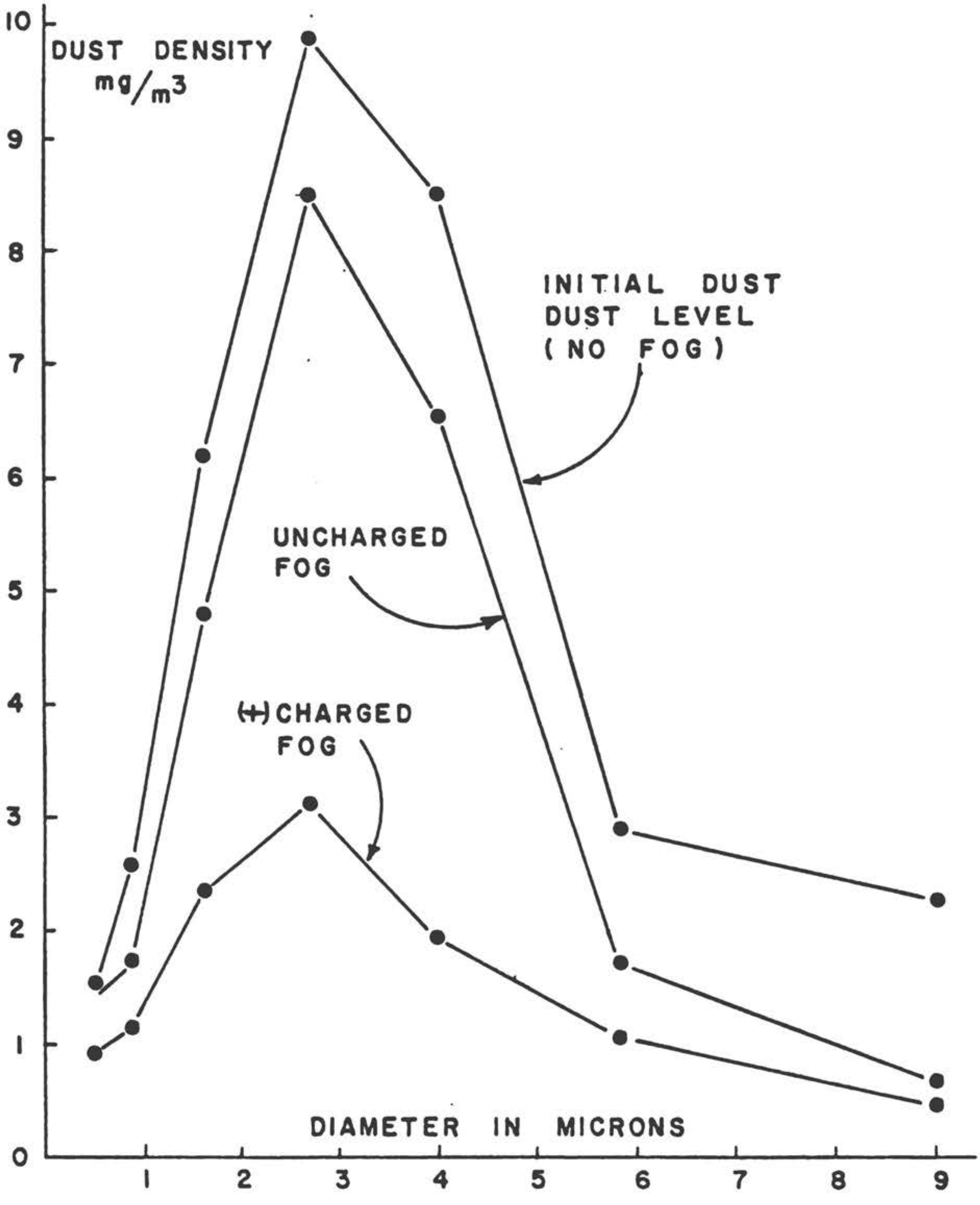
FIGURE 10 Dust Density versus Size, with and without Fogging (foundry dust).



MATERIAL (FOUNDRY DUST) CONTINUOUS OPERATION

DUST AIR FLOW 50 SCFH

FOG WATER FLOW 30 ml/min (0.475 gal/hr)

(10)

FIGURE 11 Application of Charged Fog to Control of Bauxite Dust.

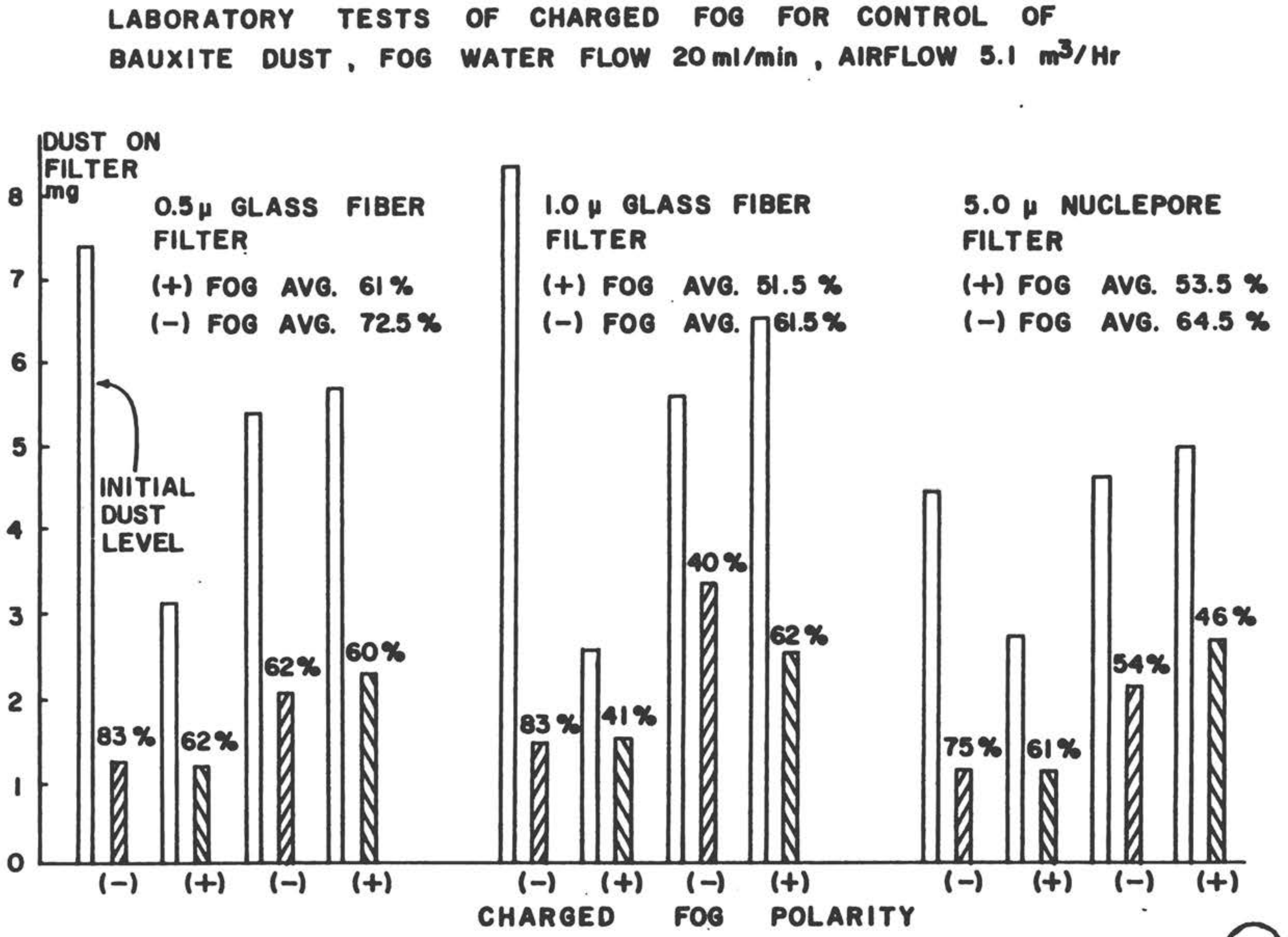


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FIGURE 12 Application of Charged Fog to Control of Grain Dust.

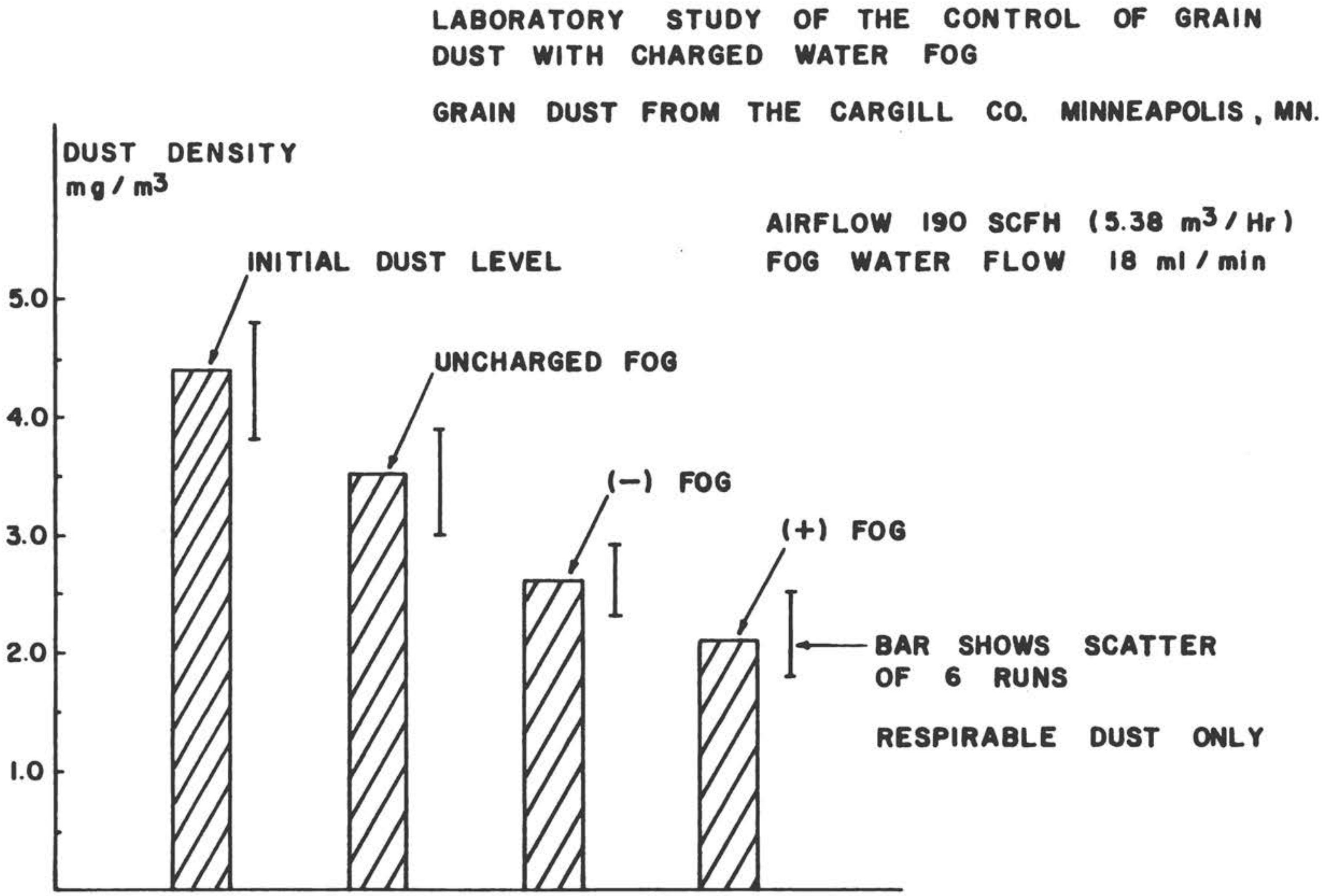

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FIGURE 13 Coal Tar Volatile Particulate Density versus Size with and without Fogging (coking coal).

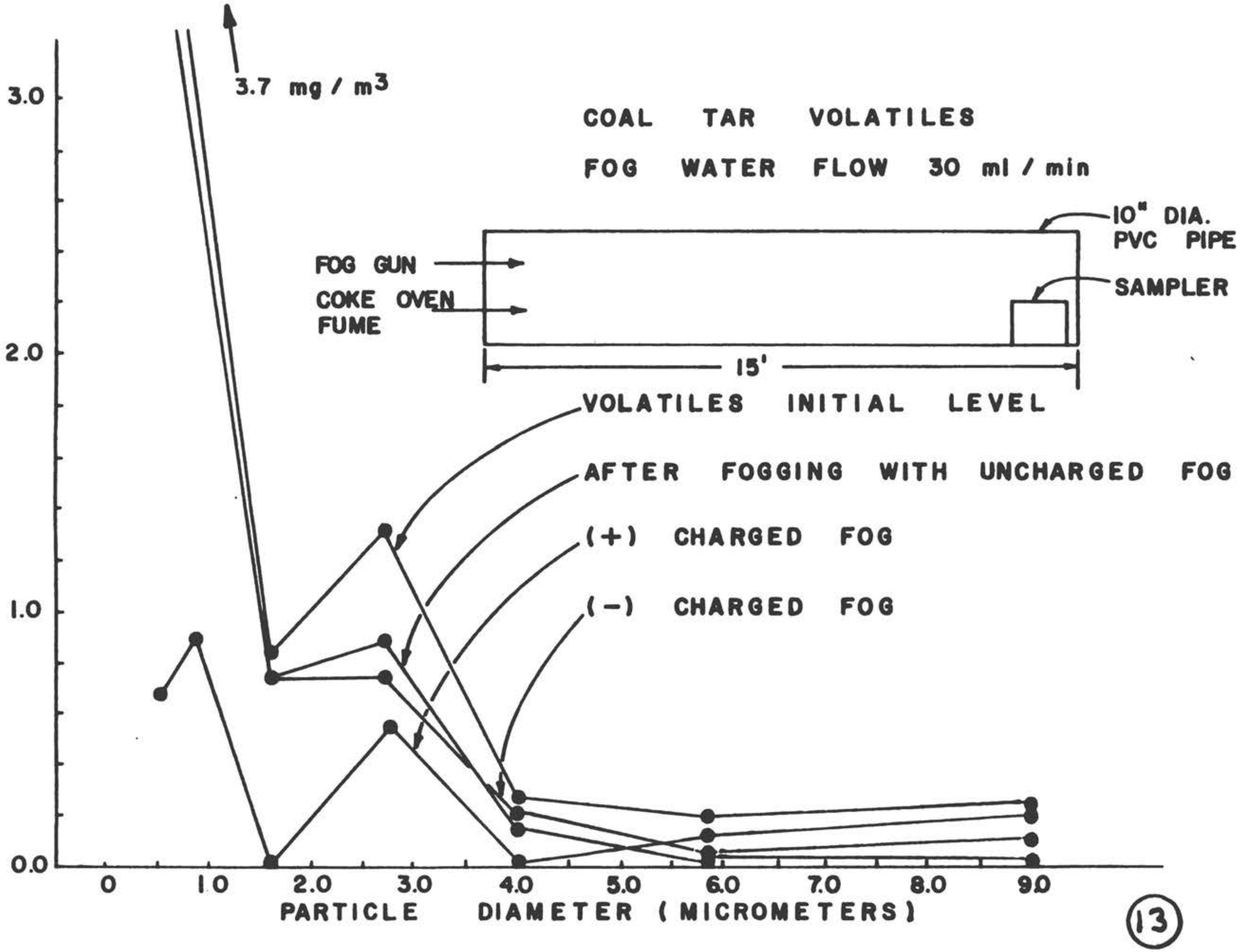

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FIGURE 14 Effect of Charged Fog on Coke Oven Vapors.

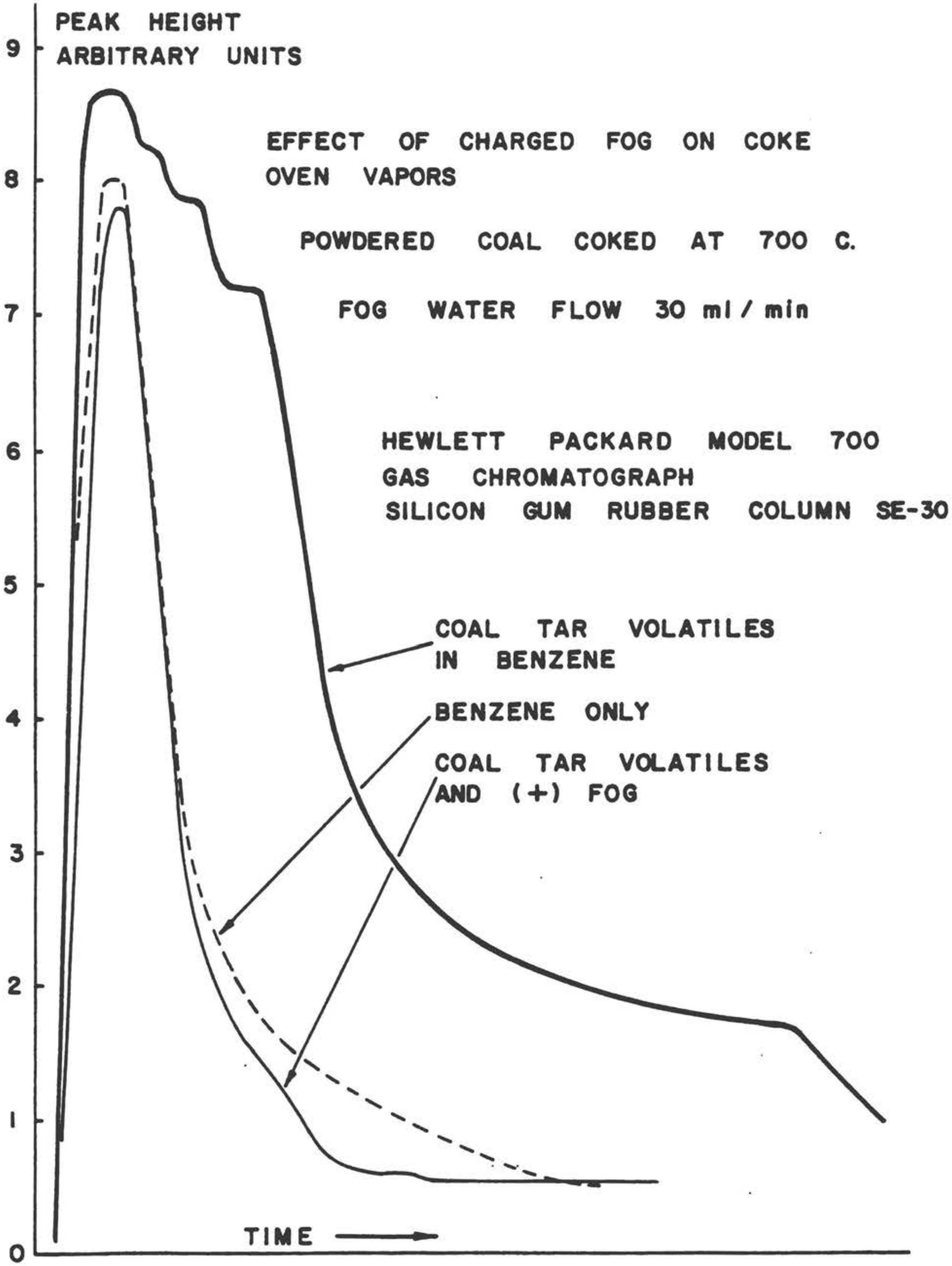

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FIGURE 15 Application of Charged Fog to Control of Cotton Dust.

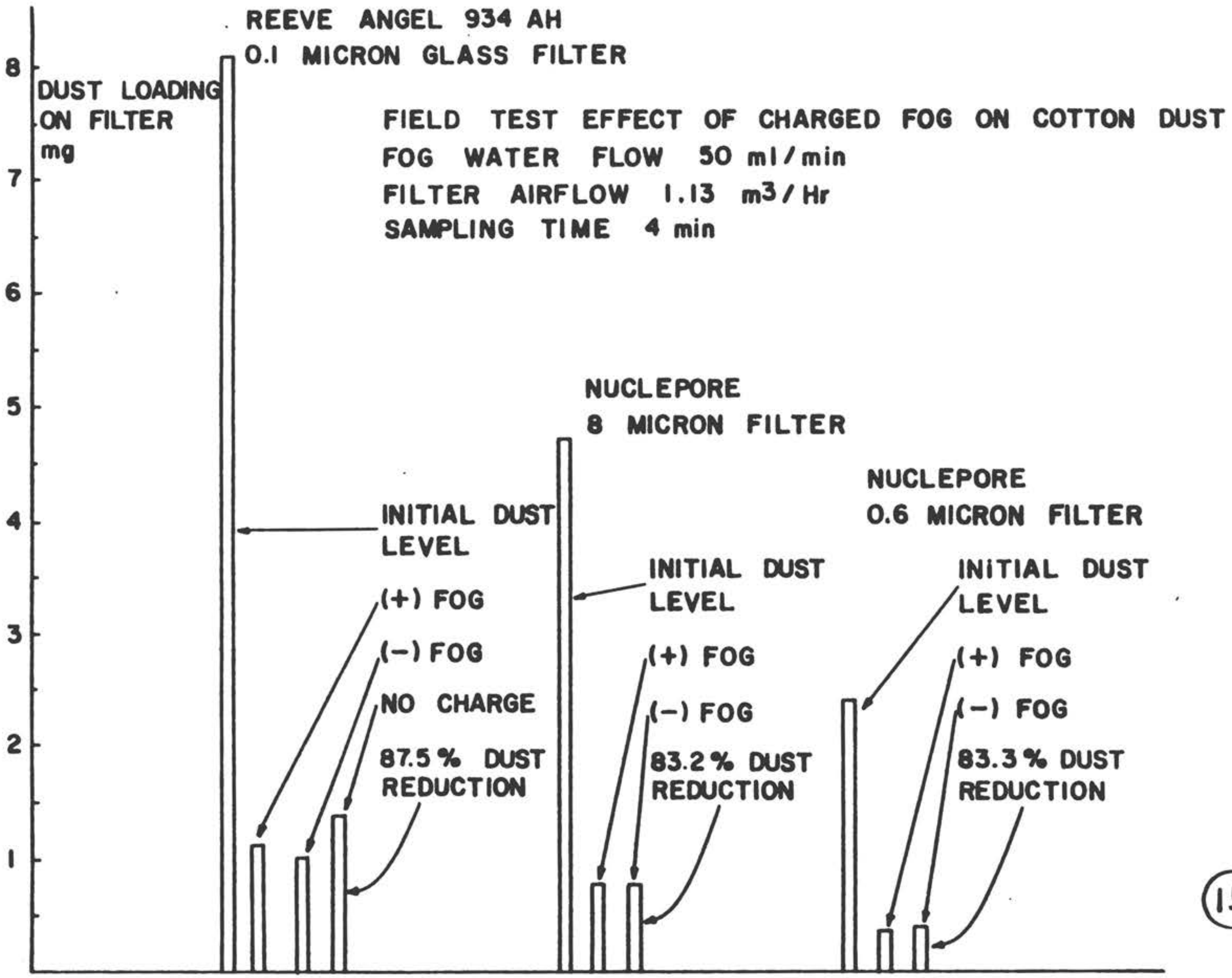

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FIGURE 16 Application of Charged Fog to Control of Cotton Brack.

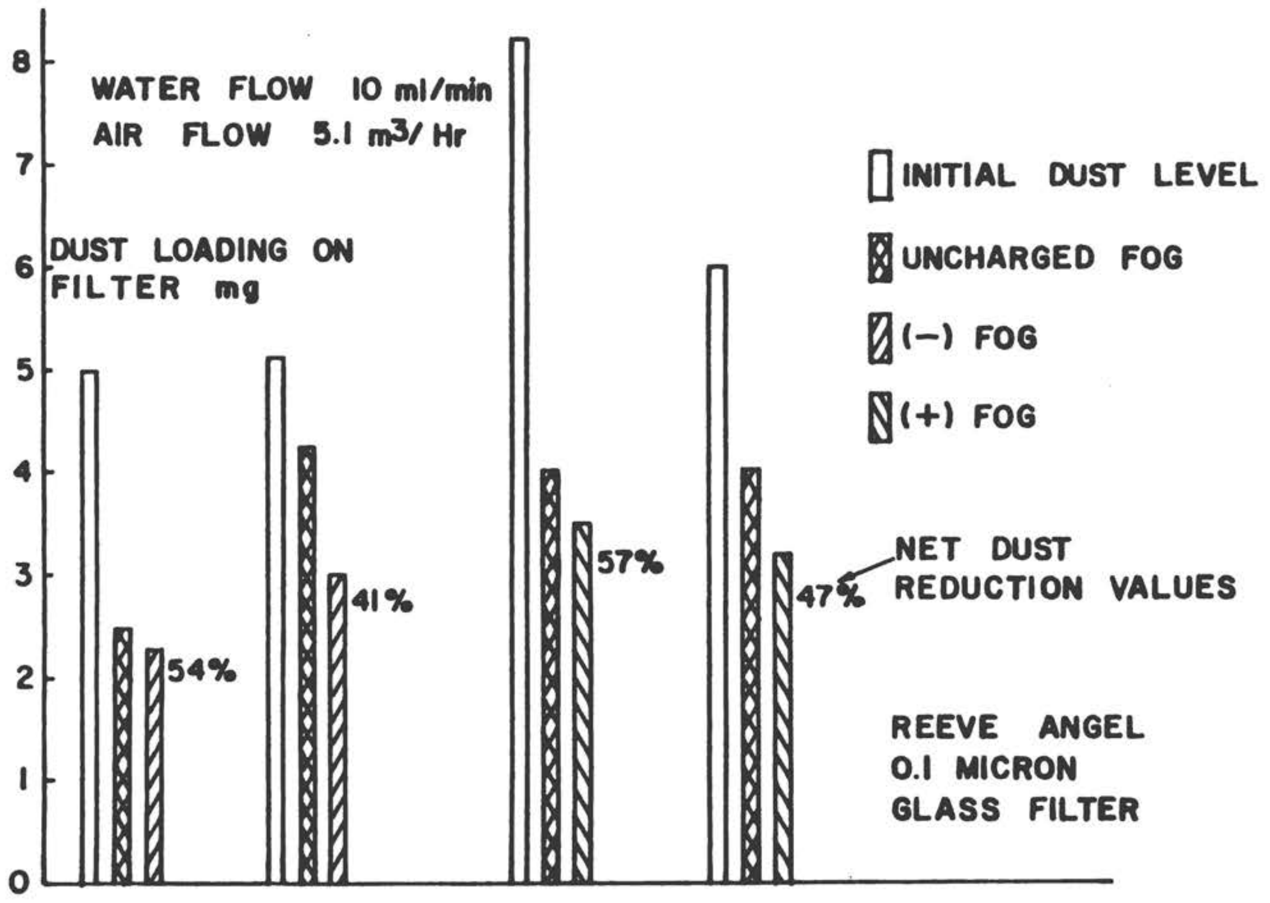

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FIGURE 17 Welding Smoke/Fume Control and Test System.

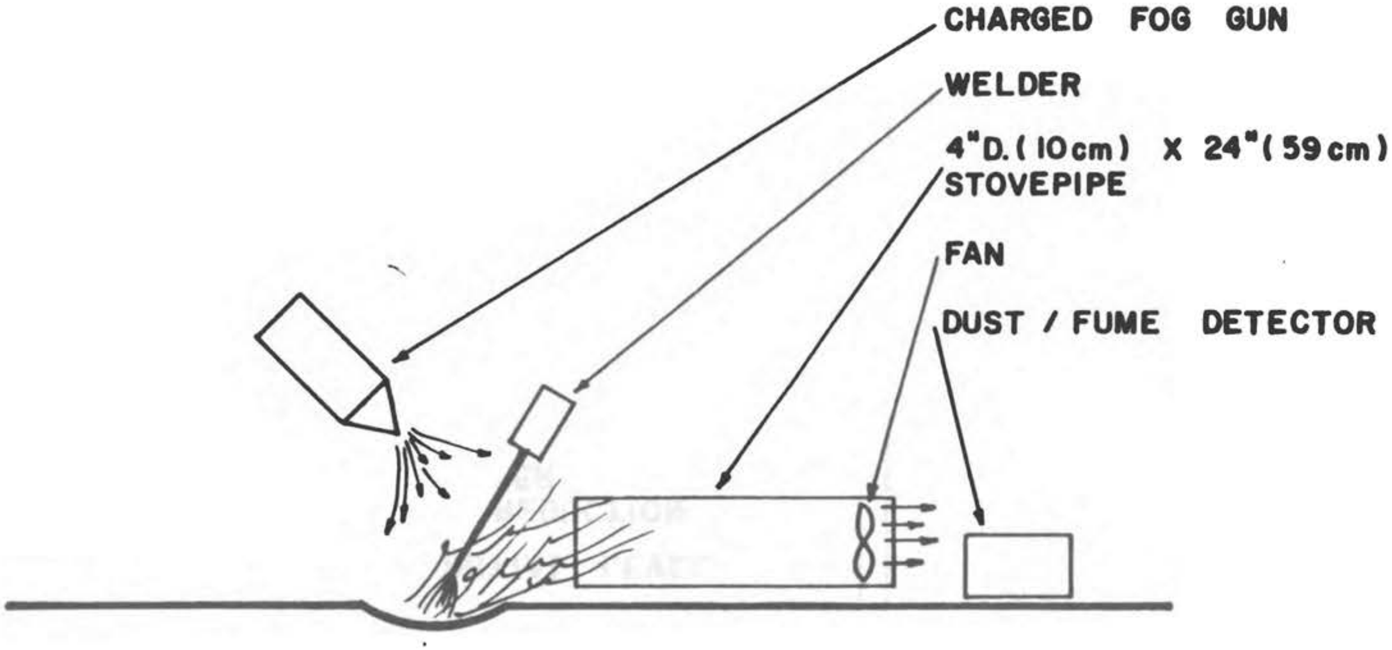

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FIGURE 18 Application of Charged Fog to Control of Welding Fume.

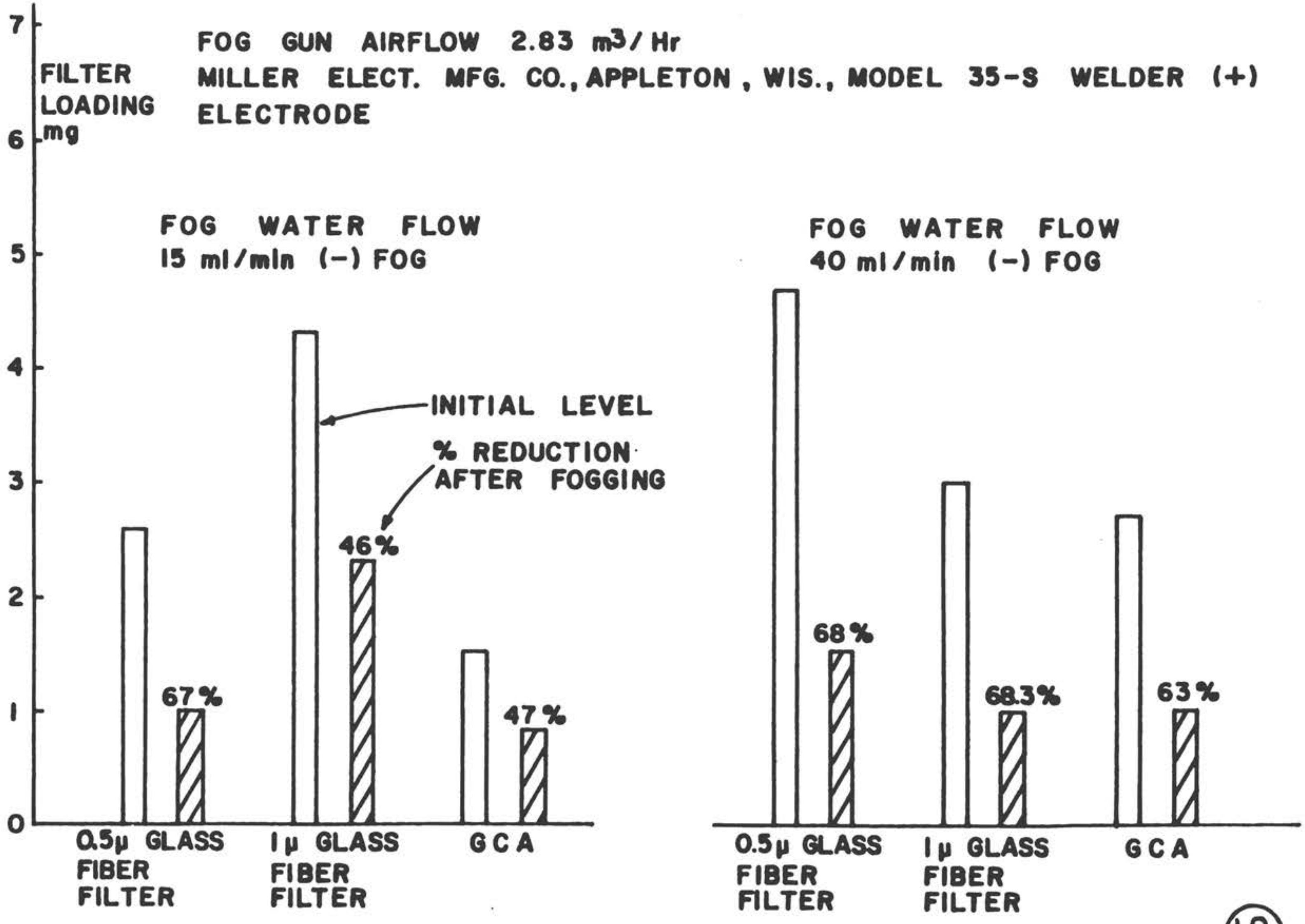

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FIGURE 19 Transvector and Fog Gun System for Control of SO_2 and Dust Emissions.

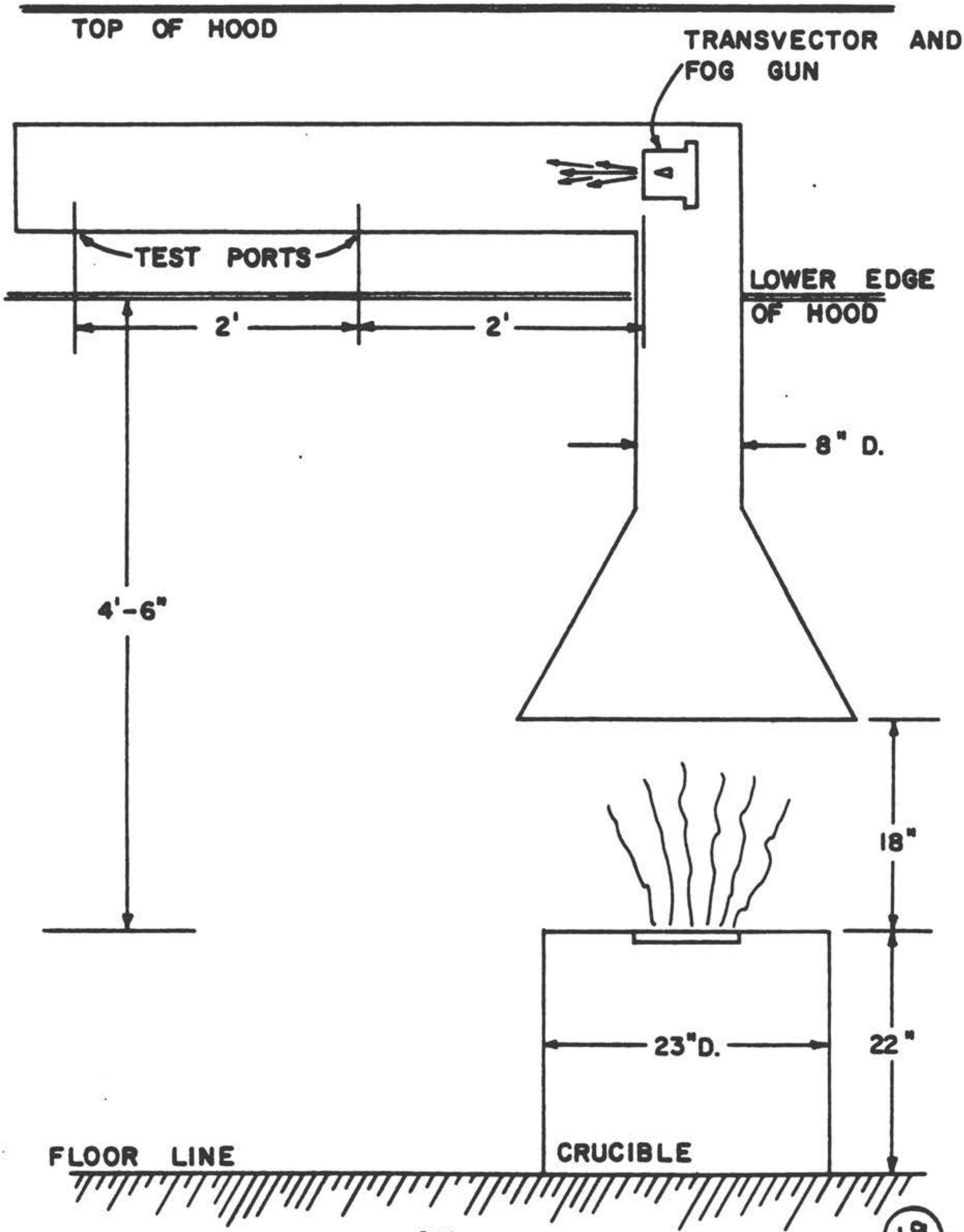

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FIGURE 20 High Temperatures, Charged Fog Test System.

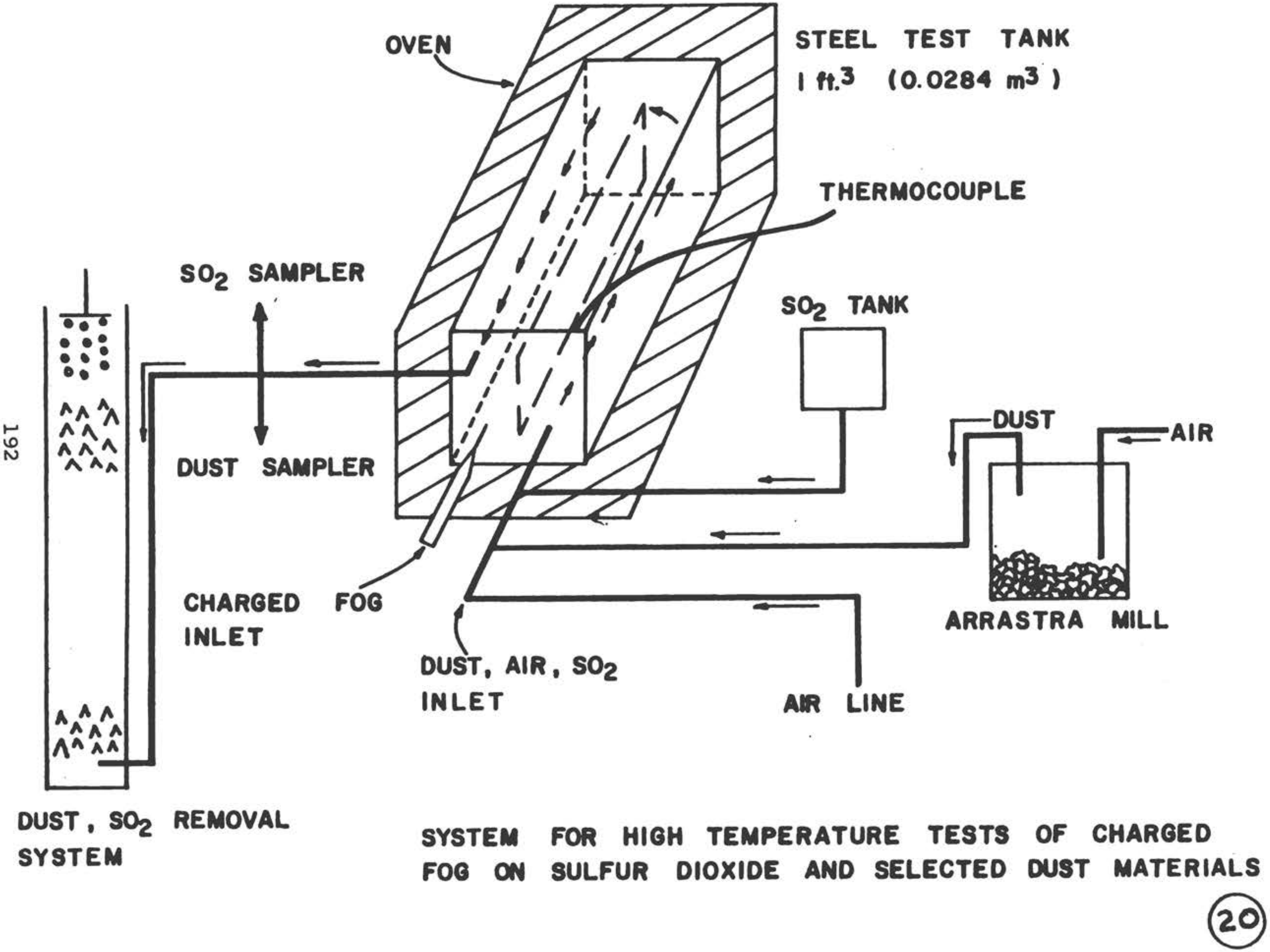

FIGURE 21 Control of SO_2 with Charged Water Fog at Various Temperatures.

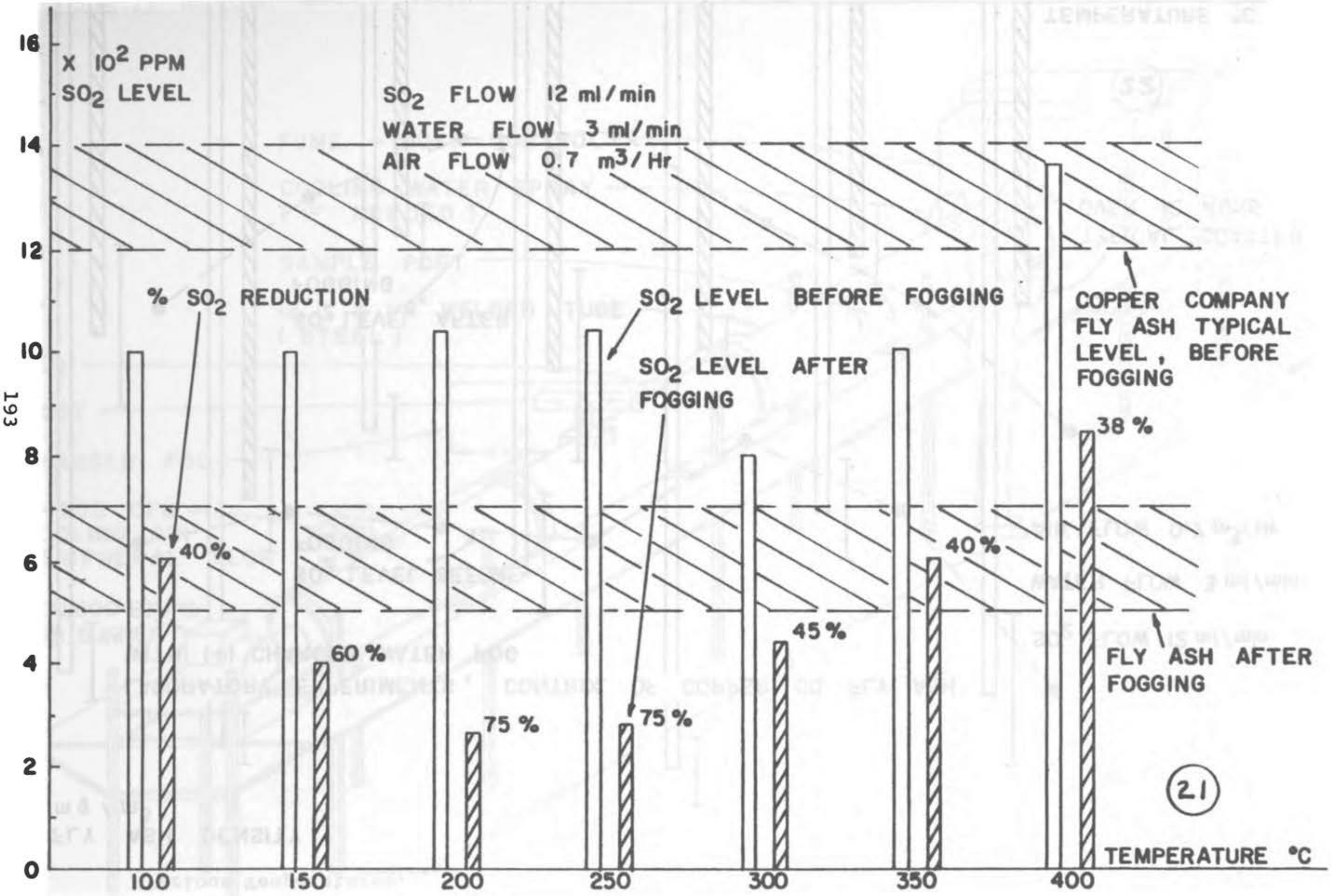

FIGURE 22 Control of Copper Company Fly Ash with Charged Water Fog at Various Temperatures.

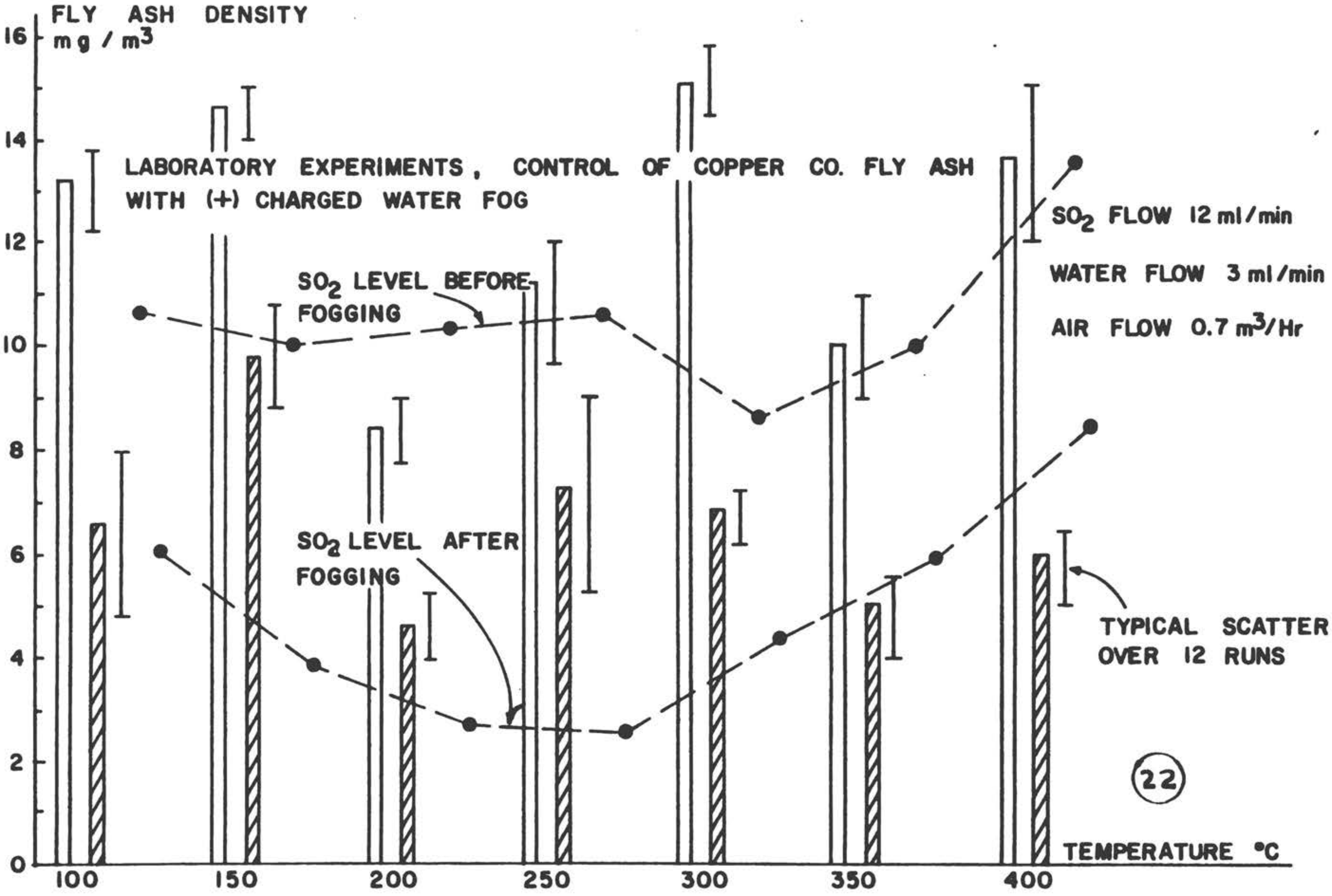

FIGURE 23 Anaconda Test Facility.

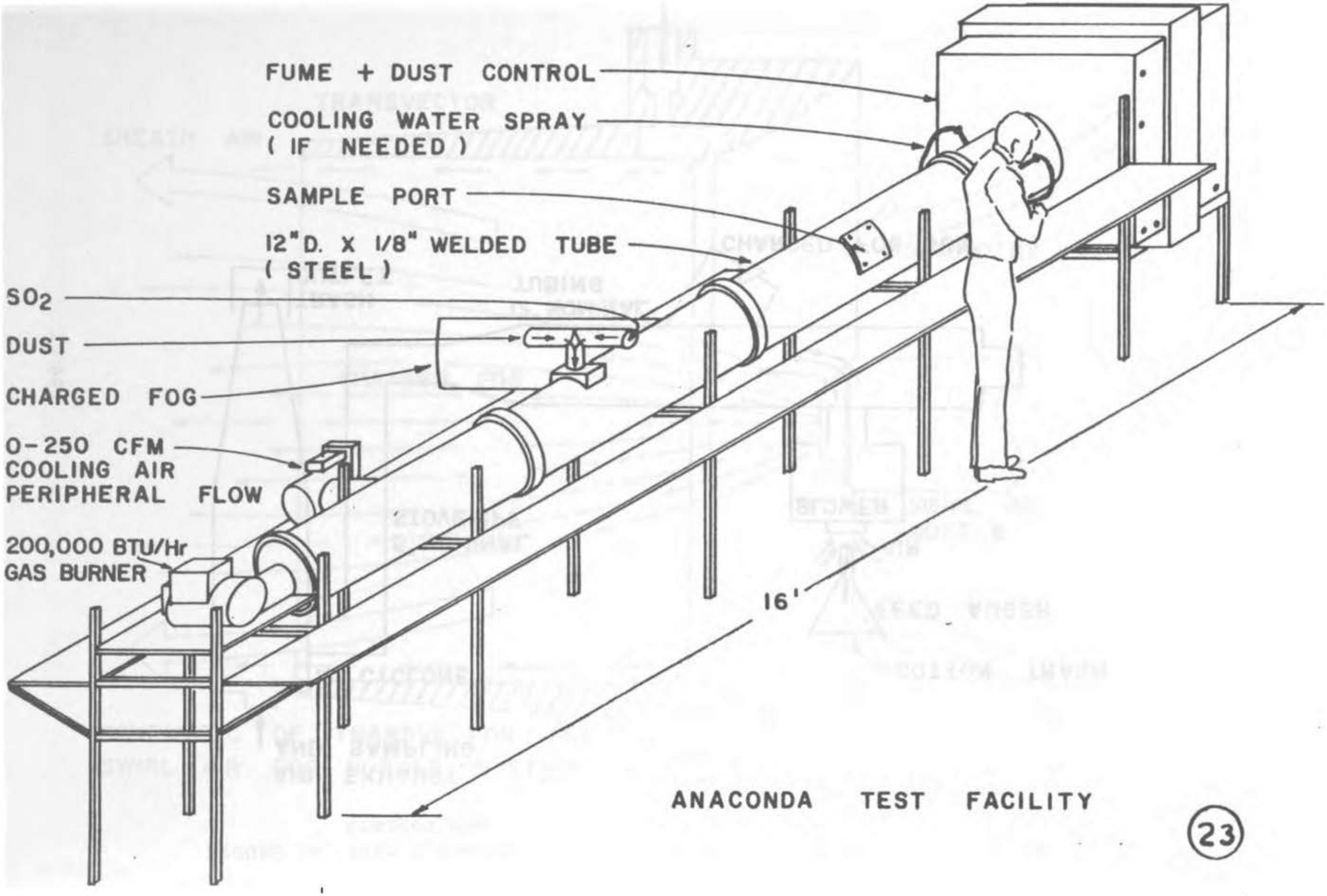

FIGURE 24 Test System for Improvement of Cyclone Collectors by Means of Charged Fog.

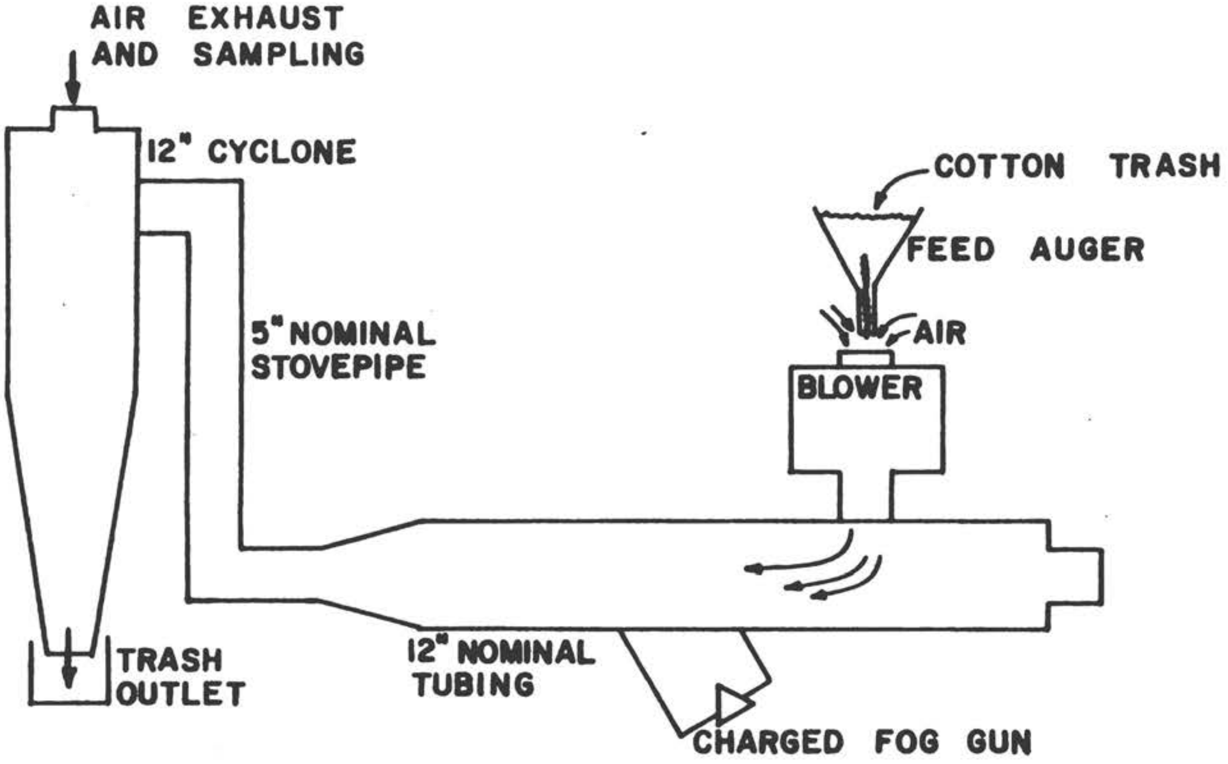

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FIGURE 25 Transvector -- Fog Nozzle System.

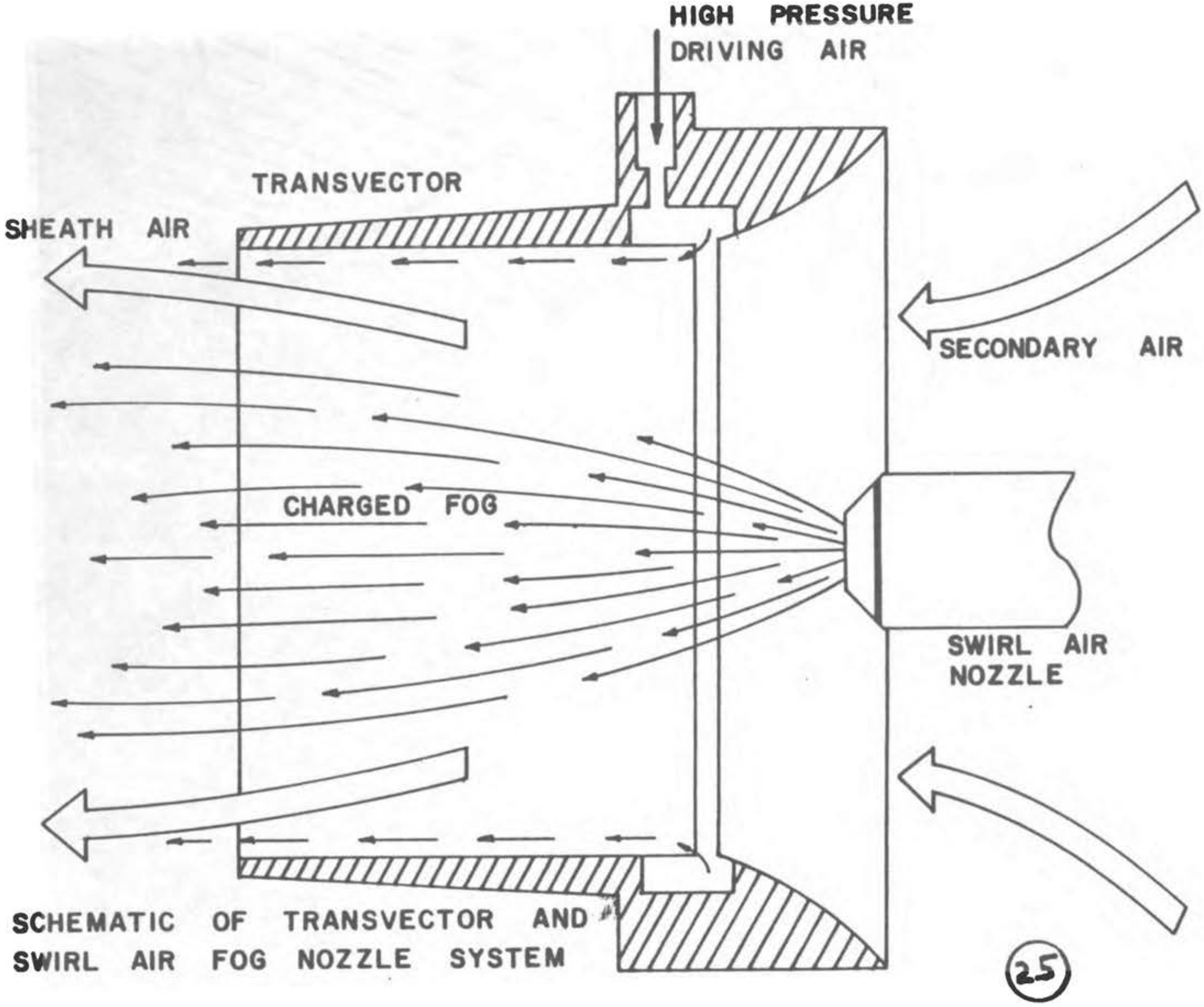

FIGURE 26 Transvector -- Fog Nozzle System in Action.

FIGURE 27 Large Dust Source with Charged Fog "Off."

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FIGURE 28 Large Dust Source with Charged Fog "On."

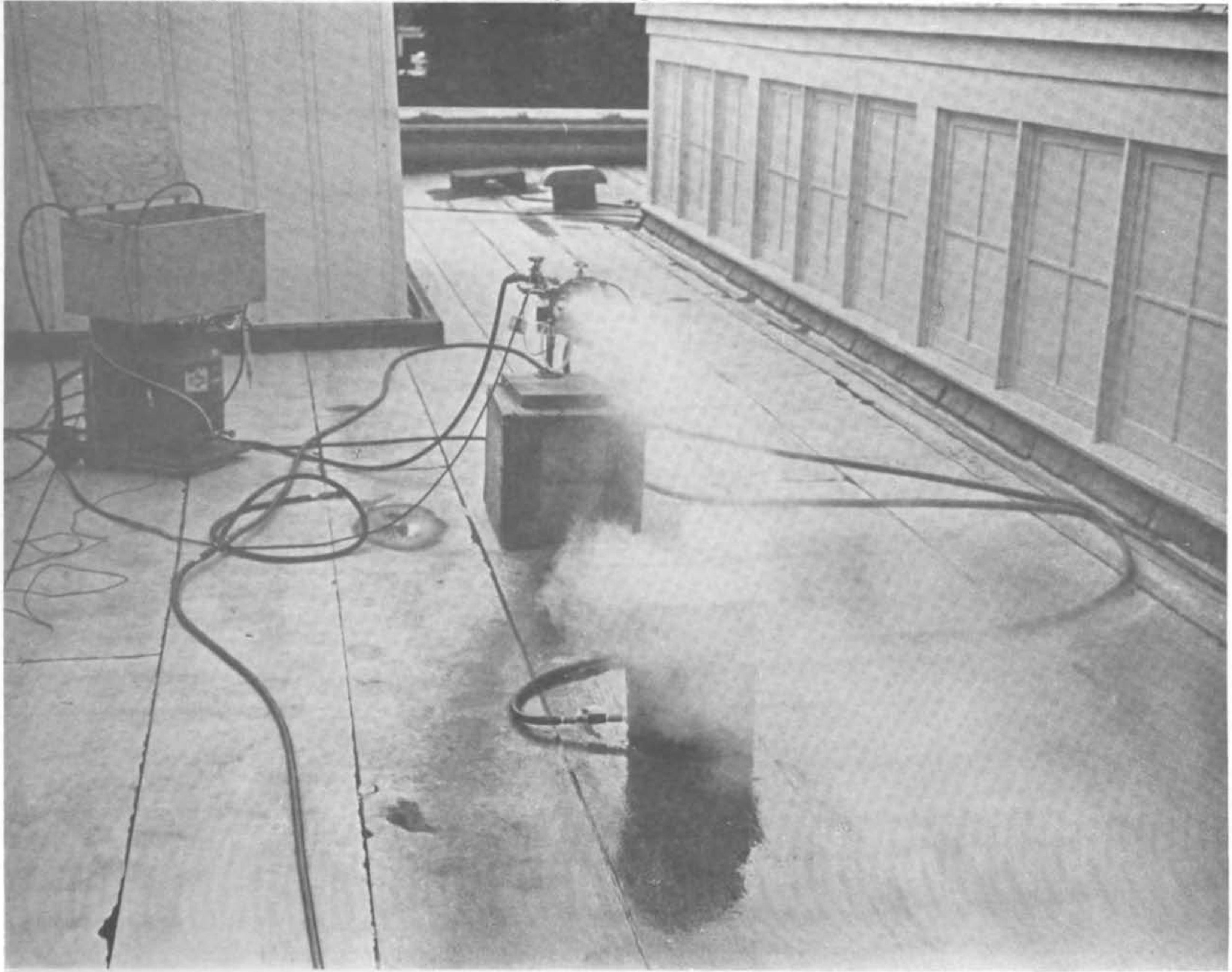

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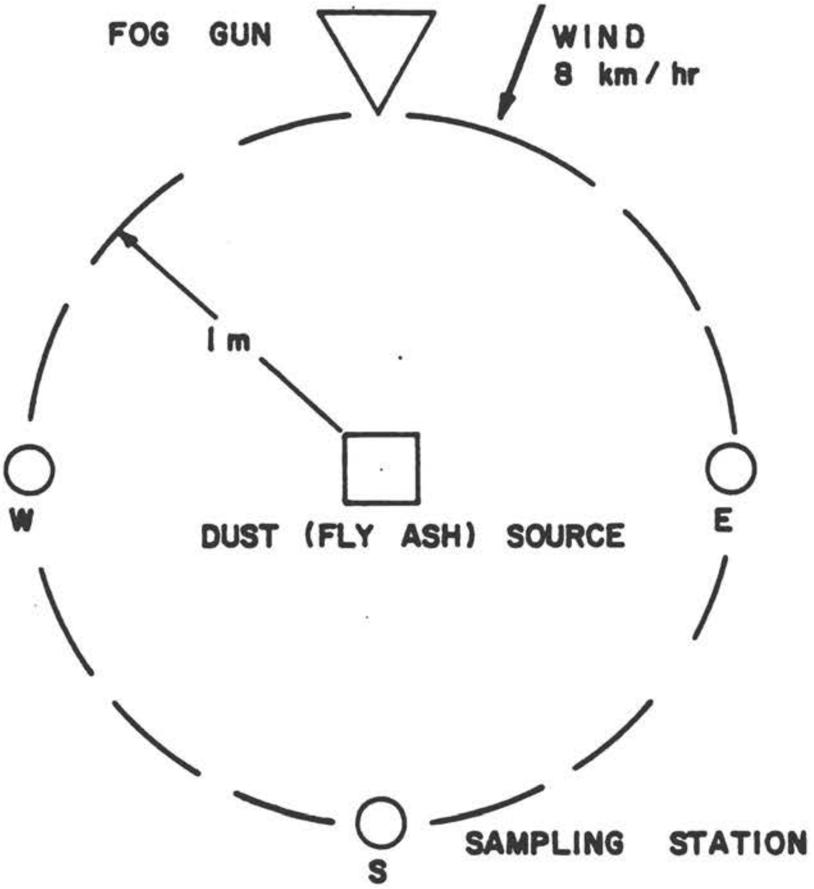
FIGURE 29 Test Data Suppression of Dust by Charged Fog.



STATION	E	W	S
DUST LOADING AVERAGE OF 4 RUNS	2.23 mg/m^3	2.0 mg/m^3	3.48 mg/m^3
DUST LOADING WITH (+) FOG 3 GAL./min	0.2	0.0	1.1
NET REDUCTION	91 %	100 %	68.4 %

OUTDOOR TEST OF CHARGED FOG FOR DUST REDUCTION

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FIGURE 30 Test Set-up at Electric Steel Casting Company.

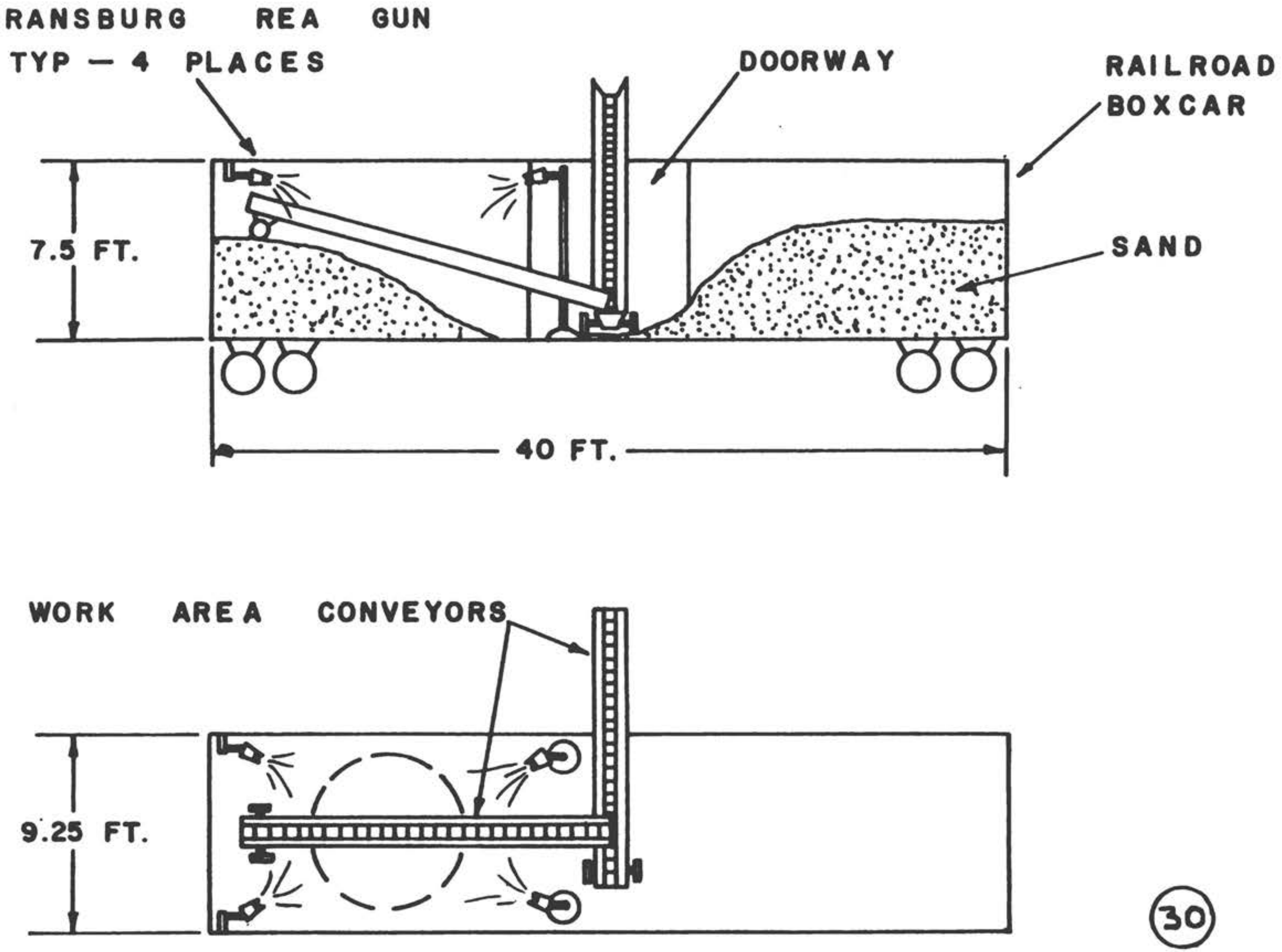

FIGURE 31 Effect of Charged Fog on Respirable Dust and Free Silica.

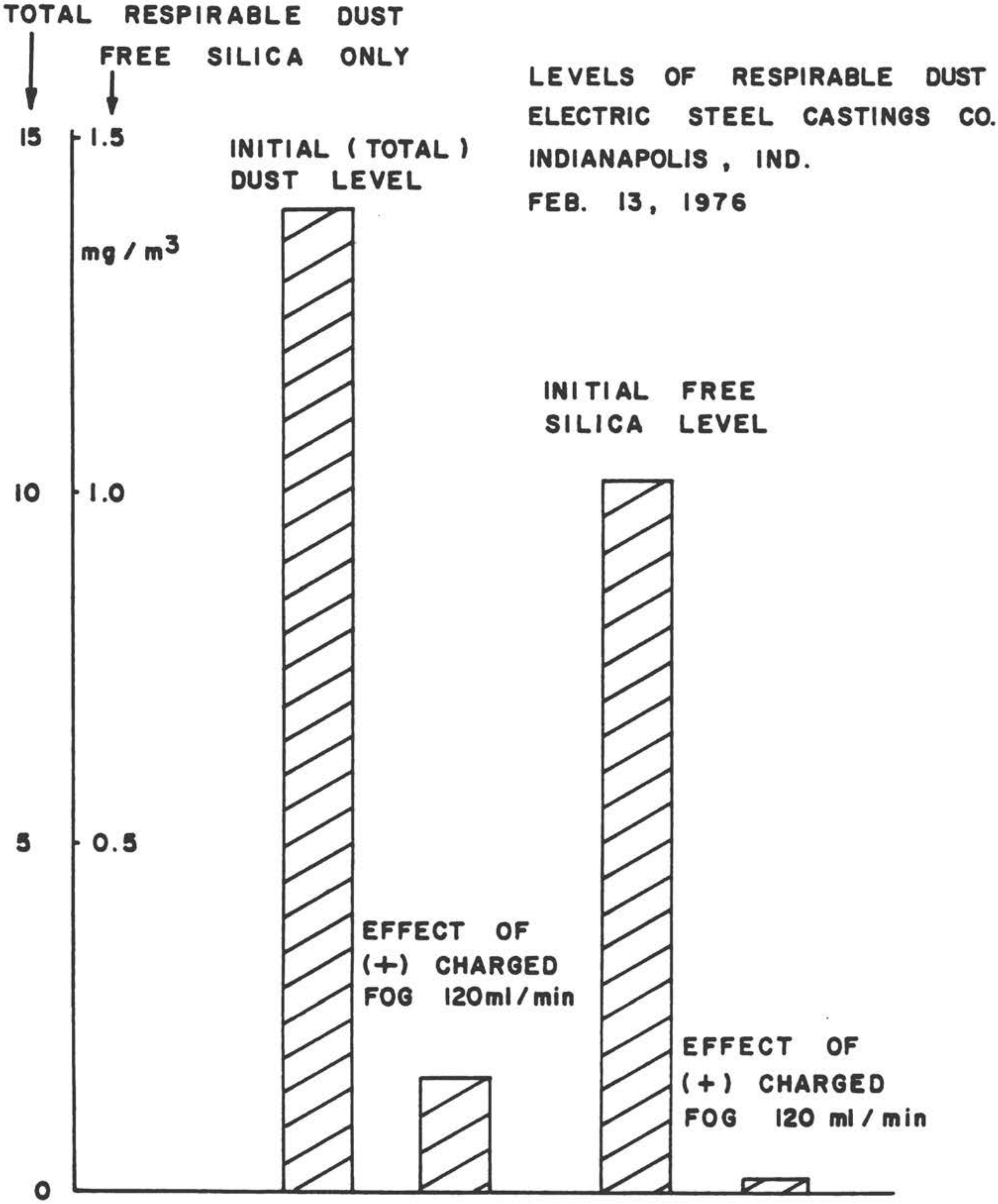

FIGURE 32 Test Set-up at Gates Learjet.

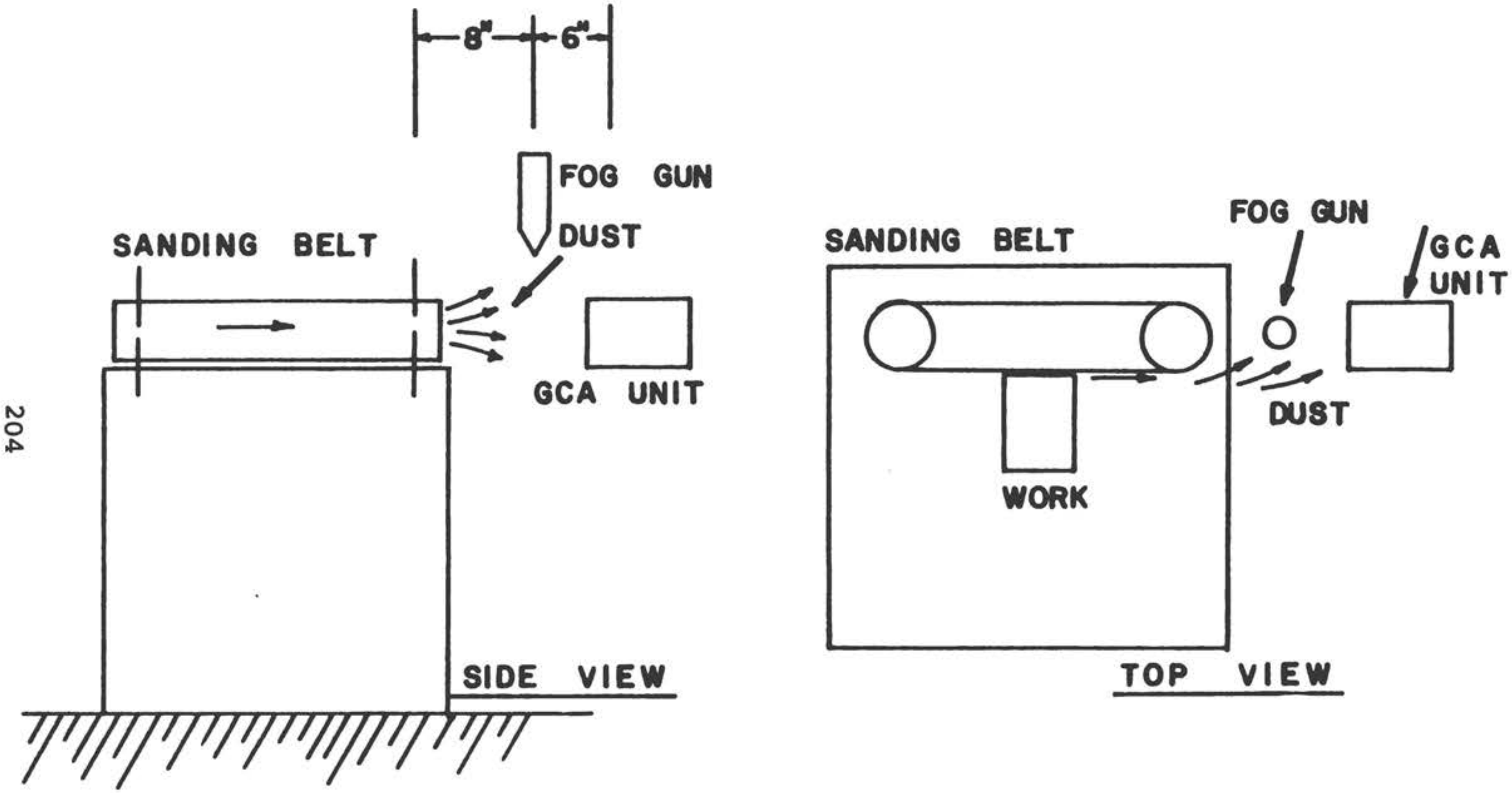

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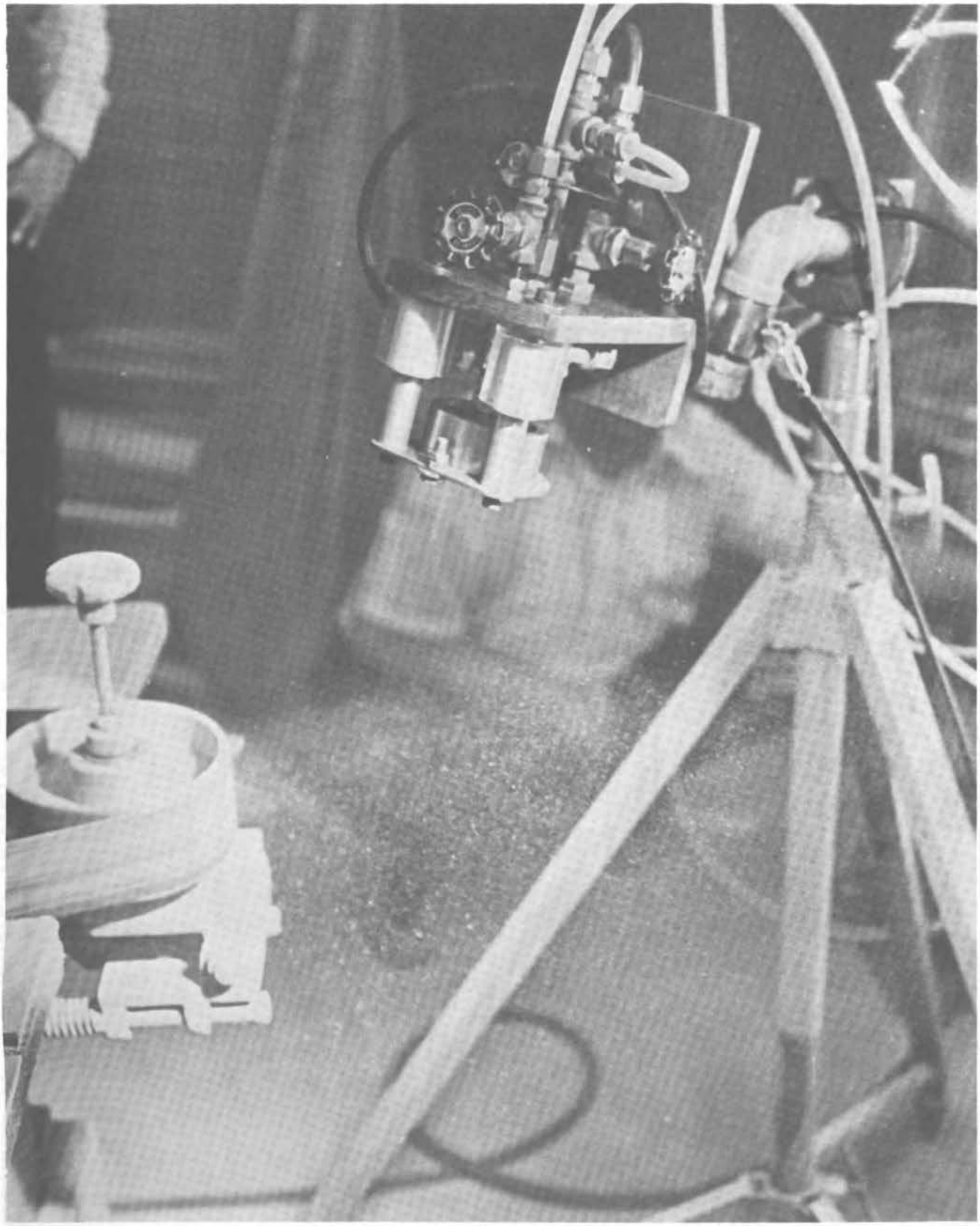
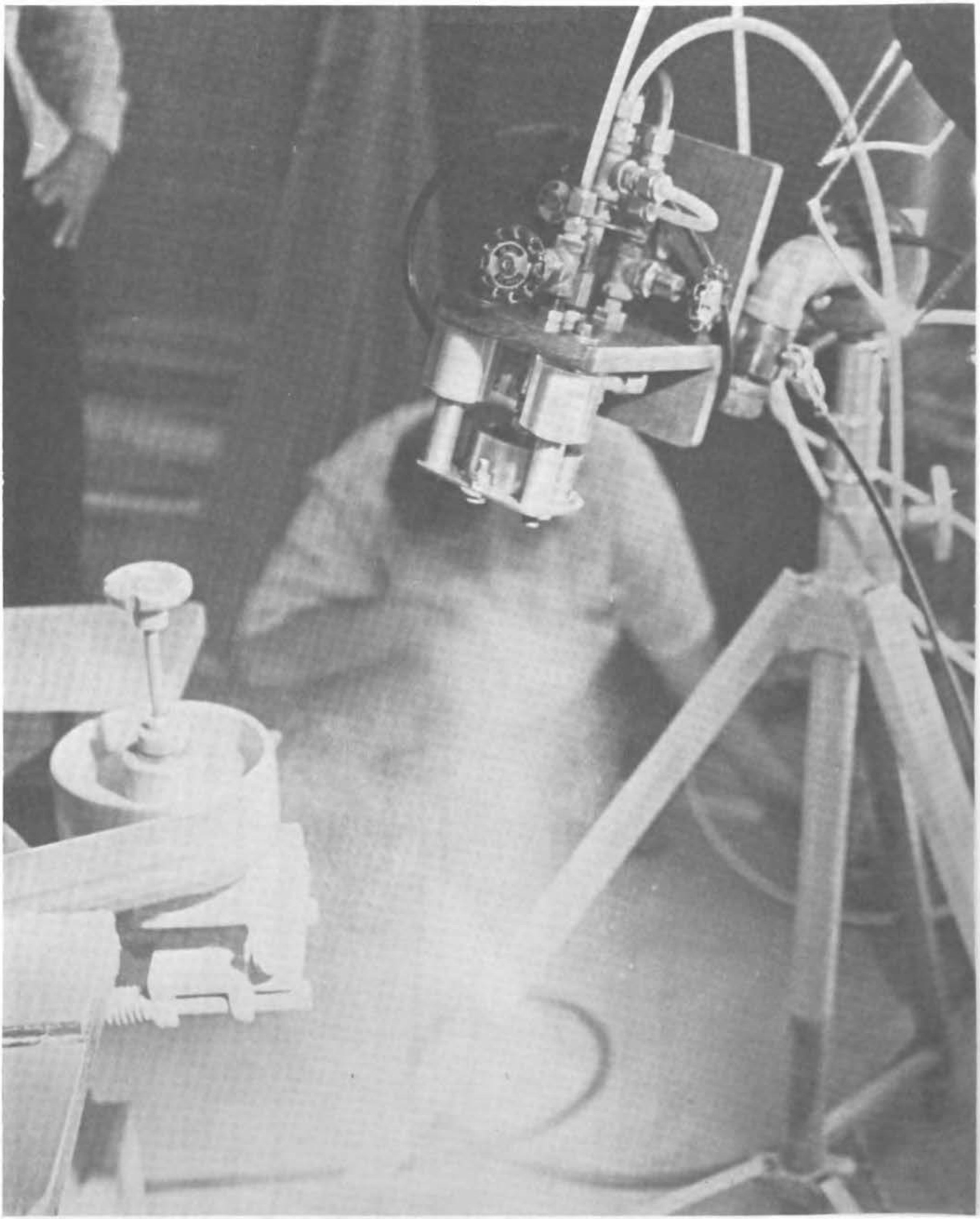
FIGURE 33a Standing Dust Flow without Charged Fog.



(33A)

FIGURE 33b Effect of Charged Fog on Sanding Dust.



33B

FIGURE 34 Sandblaster in Operation without Charged Fog.

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FIGURE 35 Effect of Charged Fog on Sandblasting Dust.

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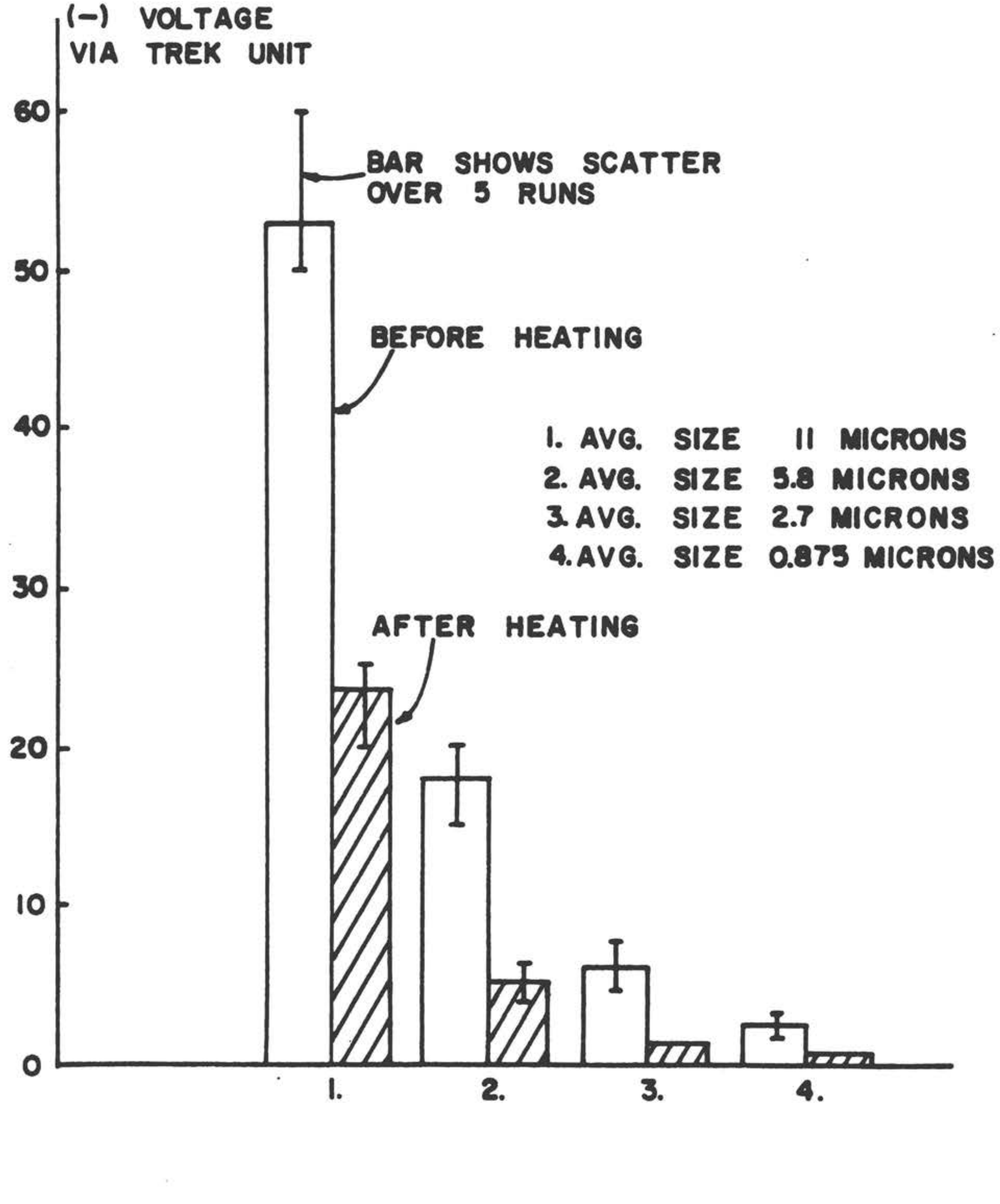
FIGURE 36 Effect of Heating to 250°C on Charging Behavior of Pure Quartz.



(36)

INDUSTRY VIEWS ON THE PROBLEMS OF GRAIN ELEVATOR EXPLOSIONS

by James E. Maness
Director of Technical Services
National Grain and Feed Association

presented at

International Symposium on
Grain Elevator Explosions
July 11-12, 1978

The grain and feed industry has long had and continues to have a primary interest in the incidents, causes and means to minimize and prevent grain dust explosions. While the basic ingredients for the occurrence of dust explosions have long been understood to be an ignition source, the fuel (grain dust), oxygen and a confined volume, many variables and combinations of conditions affecting an explosion are unknown. Today these unknowns still leave unresolved how best to minimize the potential for fires or explosions in grain and feed facilities. Because of the many difficulties in determining the causes and means to prevent explosions, the grain and feed industry seeks additional research efforts to shed new light and additional knowledge on the dust explosion phenomenon. Needed research efforts have been identified by the grain and feed industry and are outlined in Appendix A.

The grain and feed industry comprises approximately 10,000 grain elevators and approximately 7,000 feed producing firms. Table I lists the number of grain storage facilities by types of establishments. Many facilities perform both grain merchandising and feed manufacturing functions at a single establishment and would be accounted for more than once in any survey indicated in Table I. Grain elevators range in size from small country elevators up to large inland and export terminals. The number of country elevators has been estimated by the National Grain and Feed Association to be 9,472, along with approximately 413 inland terminals, and 82 export terminal elevators. Grain elevators vary in design, size, operational methods and ownership ranging from small, single independent and cooperative elevators, to major companies with a chain of elevators. It is interesting to note that almost 95% of grain elevator facilities are country elevators. The characteristics of grain elevator facilities are different from elevator to elevator in that each elevator is a custom designed facility. While elevator facilities appear similar in operation and equipment used, custom design of the facilities make each unique. The economics of each facility will vary according to their size and type of operation. While each facility differs, the industry recognizes the need to seek means to prevent and minimize the potential for explosions and fires.

The U. S. grain production in 1977 exceeded 12 billion bushels with over 8.8 billion bushels sold off-farm. Nearly all of the grain sold off-farm was handled in the grain marketing system. The grain and feed industry dries, conditions, processes, handles, stores, and markets the grain sold off-farm. Table II lists the 1977 grain production in the U. S. by commodity. The importance of the grain and feed industry to the U. S. balance of trade is shown in Table III. The export of grain, feed, oilseeds and products handled in the grain marketing system accounted for over two-thirds of the total U. S. export value of all agricultural exports in 1977. Agricultural exports exceeded imports by over $10.6 billion in 1977, which represents a significant contribution to our balance of trade. The contribution in 1978 is forecasted to be $12 billion.

Because of the importance of grain marketing to the domestic economy and its contribution to the balance of trade and value of the U. S. dollar in world markets, research is needed to correctly identify the actions to be taken to minimize the potential for the occurrence of fires and explosions in grain elevator facilities. Research identifying needed actions to minimize the potential for a fire or explosion in grain and feed facilities must consider both the technical and economic feasibility of the identified action. Retrofitting existing facilities to minimize fire or explosion potential will be more difficult than designing new concepts and equipment in new construction. Thus, to obtain the degree of protection from fire and explosions in grain and feed facilities that is desired by everyone will be a long and difficult task. The process of obtaining protection from the costly and catastrophic explosions without seriously disrupting the grain marketing system is a tremendous challenge to us all.

Two sequences of events exist in a catastrophic elevator dust explosion. The first is the occurrence of the primary explosion which most often takes place inside the elevator handling equipment. The second action occurs when the primary explosion propagates to other pieces of handling equipment or to the open spaces within the elevator. The possibility of a propagation of a primary explosion into the open spaces of an elevator where dust is rarely in suspension in air at or near explosive concentrations has been receiving a great deal of attention by government regulators. The prime concern in the grain and feed industry is to eliminate or minimize the potential for a primary explosion rather than to concentrate on preventing a secondary explosion. It is important to note the distinct difference between primary and secondary explosions causes and effects. The industry desires to find the means to prevent or minimize the occurrence of primary explosions in grain elevators. Housekeeping practices and means to limit the amounts of grain dust present in grain elevators serves mainly to limit the possibility of secondary explosions. While housekeeping and dust control are considered important in the grain and feed industry, industry efforts are being directed at identifying the causes and conditions present for the occurrence of a primary explosion. Dense dust clouds within the explosive concentration levels in the open spaces of elevators rarely occur in grain and feed facilities. It is more likely that the minimum explosive concentrations of grain dust would occur more often inside grain handling equipment. It is of vital importance that dust concentration levels outside of grain handling equipment be measured to determine under what operating conditions are explosions most likely to occur. Research needs to be concentrated on identifying the causes and means to prevent primary explosions rather than eliminating secondary explosions.

The efforts by the grain and feed industry to prevent the occurrence of a primary explosion are being directed at eliminating ignition sources from overheated equipment or breakdowns. Many companies are examining their safety, operating and maintenance policies and programs to find better methods to eliminate ignition sources and equipment malfunctions and breakdowns. The use of slow devices to detect equipment overloads, heat detectors on bearings, interlocking devices to shut down equipment and anti-plugging switches on handling equipment are being examined by elevator managers where workers are not present on a frequent basis to detect equipment malfunctions. This use of such devices becomes more important when elevator operations are automated. Larger terminal operations are becoming more automated to handle larger grain handling capacities. Smaller terminals, country elevators and feed mill operations rely on manual operation of equipment for start up and shut down of the equipment. At these smaller facilities equipment operators detect equipment malfunctions and are implementing improved preventive maintenance programs on grain handling equipment. The size of operation and type of facilities are two important factors in considering the most cost effective and best methods to prevent or minimize the potential for a grain dust explosion.

In addressing the known causes of elevator explosions i.e., equipment malfunctions, welding operations and abuse of company safety policies, the grain and feed industry is taking positive steps. The National Grain and Feed Association identified the following seven guidelines for facility managers for review of fire and explosion safety programs and policies. These seven guidelines attempt to address many of the known causes of elevator explosions. These following seven guidelines were listed for management consideration in implementing immediate prevention techniques against elevator explosions.

1. Hot work, such as welding and cutting, should only be performed when elevator equipment in the welding area is not in operation. Fundamental safety precautions should be taken such as ensuring that the areas are free of dust or flammable materials when welding and cutting. Fire watches should be implemented to ensure that no resultant fire occurs during and after welding. A company policy of requiring welding and cutting permits before work begins should be considered.
2. Safety training and fire drills of all elevator employees, government representatives and contractors and their employees should be an essential part of a company's safety program. Elevator safety rules and potential hazards need to be explained to all who perform work at grain elevators.
3. All companies should review their emergency procedure plans for evacuation, fire fighting and rescue operations. The plans need to be discussed with elevator employees and others frequenting elevator facilities.
4. Good communications should be emphasized between elevator management, employees and government representatives present at elevator facilities, especially in regard to safety rules, fire drills and emergency plans.
5. A comprehensive preventive maintenance program is a necessary part of the elevator's management safety program.
6. Good housekeeping should be reemphasized.
7. "No smoking" rules should be rigidly enforced in and around elevators.

There are many experimental difficulties in testing for minimum explosive concentrations of grain dust. There exists a need to gather more information and knowledge of the grain dust explosion phenomenon. The parameters of minimum ignition temperature, minimum explosive concentration, minimum ignition energy, explosion pressure and rate of pressure rise are difficult to measure and translate from laboratory test to the actual elevator operations. In addition, the explosibility of the grain dust is dependent upon size, shape, moisture content, density and chemical composition of the dust. The difficulties of experimentation on dust explosibility are complicated by the need to accurately determine all of the parameters affecting the explosion event during each explosion. More research into the explosibility of grain dust with documentation of all the parameters may lead to the discovery of the sets of parameters to which industry should apply efforts to minimize the potential for a dust explosion.

There have been many theories or opinions offered as to the causes of dust explosions. For each theory offered there are many exceptions that do not fit the theory. Low humidity has been offered as a contributing factor to explosions. Explosions have occurred during times of high relative humidity with no detectible increase in explosion incidence in drier areas of the country. The relative humidity has less impact on moisture in grain dust than the moisture content of the grain. The practice of returning grain dust to the grain stream has been theorized as a significant contributing factor to grain dust explosions. Elevator explosions have occurred where grain dust was not returned to the grain stream. It is clear that preventing the practice of returning grain dust would not eliminate explosion risks. Industry dust handling practices should not be changed until we have more knowledge on the explosibility of various dust concentrations, measurement of dust concentrations present in facilities and equipment, and a determination of the benefits gained from not returning dust to the grain stream. Taking grain dust out of grain and not returning it to the grain stream will not necessarily reduce the presence of dust in elevator and equipment appreciably. To act on theories without knowledge would impose unjustified cost in grain handling operations. Action based on theory may be counterproductive in causing a less than vigorous search or approach to examining the many research gaps that exist for the grain dust explosion phenomenon. New research efforts may uncover areas or concerns where greater benefits can be realized in reducing the potential for an explosion or fire.

There is a great concern in the grain and feed industry that changes in elevator practices and operations based on theories or incomplete and inadequate analysis and research into elevator explosion problems may result in wasted spending with little to no reduction in the occurrences of explosions. There is an absolute necessity to deal and work with facts and perform research in areas of unknowns. Many questions have been raised which need investigation and answers. Only through research can questions, for which no one has the answers, receive a proper assessment. This is where researchers can play major roles. By correctly identifying facts and making these facts available to government and industry, both government and industry can act responsibly in utilizing the facts. Research will help ensure that the correct course of action is taken without ending up on erroneous paths.

Explosions represent enormous costs to the industry. Business is lost while the facility is replaced. Following good explosion prevention procedures is recognized as good business by industry members. Everyone in the industry recognizes the importance and need to protect their employees', friends' and relatives' lives and business investments from elevator explosions. The industry stands ready to assist all who can and will help to seek the needed answers. The industry will continue to pursue the answers through its own efforts.

Working together, the industry, government, and researchers can find ways to reduce dust explosion risks. In the interim, the industry will continue to implement known solutions to known problems. In conclusion, the need for additional research is vital. Theories and opinions will contribute little to identifying the correct actions to be taken in minimizing the potential for grain dust explosions or fires.

TABLE I

NUMBER OF GRAIN STORAGE FACILITIES BY
TYPES OF ESTABLISHMENTS

Types of Establishments		Storage Facilities (number)
Off-farm Grain Storage Facilities 1)		15,065
Formula Feed Establishments		10,840
- 1975 Survey --- 6340 2)		
- 1969 Survey --- 4500 3) estimated establishments producing below 1,000 tons per year not included in 1975 Survey		
Processor Facilities		729
- Flour and Other Grain Mills 4)	457	
- Wet Corn Milling 4)	41	
- Cereal Breakfast Foods 4)	137	
- Soybean Oil Mills 5)	94	
Port Terminal Elevators (includes 2 floating rigs approved for operation in automatic mode) 6)		82
Inland Terminal Elevators 7)		413
Country Elevators 8)		9,472

SOURCES:
1) U.S. Department of Agriculture; Grain Stocks; Economics, Statistics, and Cooperatives Service. January 25, 1978, page 43.
2) U.S. Department of Agriculture; Structure of the Feed Manufacturing Industry, 1975 -- A Statistical Summary; Economics, Statistics, and Cooperatives Service; Statistical Bulletin No. 596; February 1978. page 28 and 43.
3) Shannon, Larry, Jr.; Richard W. Gerstle; P.G. Gorman; D.M. Epp; T.W. Dewitt, and R. Amick; Emissions Control in the Grain and Feed Industry -- Volume I - Engineering and Cost Study; Midwest Research Institute, Kansas City, MO; prepared for U.S. Environmental Protection Agency. Contract No. 68-02-0213. December 1973. page 36.
4) 1972 Census of Manufacturers, Industry Series, Grain Mill Products, SIC Industry Group 204. Bureau of Census, U.S. Department of Commerce. MC72(2)-2PD. April 1975. page 20D-6 and 20D-7.
5) 1972 Census of Manufacturers, Industry Series, Fats and Oils, SIC Industry Group 207. Bureau of Census, U.S. Department of Commerce. MC72(2)-20G. January 1975. page 20G-6
6) U.S. Department of Agriculture, Federal Grain Inspection Service, Compliance Division, January 27, 1978.
7) Standards Support and Environmental Impact Statement, Volume I: Proposed Standards of Performance for Grain Elevator Industry, U.S. Environmental Protection Agency; Research Triangle Park, N.C. January, 1977. page 2-5.
8) Statement of the National Grain and Feed Association, Comments Submitted on U.S. Environmental Protection Agency, Proposed Standards of Performance for New Stationary Sources --Grain Elevators; Developed and Approved by the Association's Environmental Quality Committee; Review and Analysis drafted by James E. Maness and Harvey L. Kiser; May 12, 1977. page 30.

TABLE II

UNITED STATES: GRAIN PRODUCED, SOLD OFF FARM WHERE PRODUCED AND PERCENT OF PRODUCTION SOLD, 1977
(1,000 BUSHELS)

Commodity	Production	Sold	Percent Production Sold
Corn	6,357,424	4,028,336	63.4%
Sorghum for grain	790,647	560,595	70.9
Oats	747,914	288,415	38.6
Barley	415,803	301,871	72.6
Wheat (all)	2,025,793	1,909,420	94.3
Rye	16,998	13,182	77.6
Soybeans for beans	1,716,334	1,690,328	98.5
Flaxseed	16,105	15,477	96.1
TOTAL	12,087,018	8,807,624	72.9

SOURCE: Field Crops (Production, Disposition, and Value, 1975-1976-1977) U.S. Department of Agriculture, Washington, D. C., CrPr 1(78), April 10, 1978.

TABLE III

U.S. AGRICULTURAL EXPORTS AND IMPORTS: VALUE BY SELECTED COMMODITY GROUPS --FISCAL YEAR 1977 AND 1978-- (BILLION DOLLARS)

	Grain and Feed	Oilseeds and Products	Other Agricultural Commodities	TOTAL
1977 Fiscal Year				
Export Value	10.174	6.418	7.421	24.013
Import Value	-	0.639	12.743	13.382
Net Export Value	+10.174	+5.779	-5.322	+10.631
Forecast 1978 Fiscal Year				
Export Value	10.9	6.9	7.7	25.5
Import Value	-	0.5	13.0	13.5
Net Export Value	+10.9	+6.4	-5.3	+12.0

SOURCE: <u>Outlook for U.S. Agricultural Exports</u>, U.S. Department of Agriculture, Washington, D. C., May 18, 1978.

APPENDIX A

RESEARCH PROJECTS AND ACTIVITIES
FOR
MINIMIZING THE POTENTIAL OF ELEVATOR EXPLOSIONS
RECOMMENDED BY THE NATIONAL GRAIN & FEED ASSOCIATION*

The National Grain and Feed Association recommends research and analysis of the following projects and activities that are identified with factors which may contribute to or cause fires and explosions in grain elevators and feed plants. Results and conclusions from the research and studies should provide new information and new understanding for the prevention and minimization of explosions and fires.

Eight major areas have been identified for study and evaluation. Major areas A through D (Part I) are recommended for government sponsorship because of general public interest and welfare in saving human life and because of the importance of grain marketing to the domestic economy and to world markets. Specific research projects under the four major headings have been identified and prioritized numerically.

Major areas A through D (Part II) include research projects and activities to be conducted by members and associations in the grain and feed industry. The research under these four major headings complement the government-sponsored research recommendations.

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* These recommendations were approved by the National's Management Team on Elevator Explosions and Fires, which is comprised of a broad spectrum of grain and feed industry managers and technical experts. The research projects and activities listed in this Appendix were presented to Secretary of Agriculture, Bob Bergland, at his request on March 6, 1978. Appendix B presents background information on National Grain and Feed Association.

The research areas, A through D, (Part I), and research projects 1 through 25 are as follows:

I. Research Projects and Activities Recommended to Government

A. Examination of the Explosion Phenomenon of Agricultural Dusts and Other Dusts Present in Grain

Over the years there has been research performed to examine the explosion phenomenon of agricultural dusts. Of principal concern to the grain industry is whether we have enough information on the properties of grain dust and its explosibility. Research which assesses what is known about explosive concentrations of dusts, ignition temperatures, flame or explosion propagation, generated explosion forces, and many other factors involved, is necessary in understanding and identifying areas and conditions in grain elevators which may need attention. Research of grain dust explosion phenomena may identify new factors and provide better information on grain dust explosions. This research needs the attention of governmental agencies and independent researchers or agents with a background in examining explosion phenomenon.

Identified Research Projects in Order of Priority

1. Study the explosion phenomenon of grain dust and other dust aerosols occurring when grain is handled in elevators.

2. Conduct fundamental research on flame and shock wave propagation through dust clouds and elevator facilities or machinery to aid in determining ways to reduce the potential of grain elevator fires and explosions or minimize the effects of an explosion or fire.

3. Adopt a uniform explosion chamber for measuring or testing the explosion characteristics of dusts. A standard explosion or combustion chamber would help in comparing the data of researchers.

4. Investigate the modeling of elevator explosions for extrapolation to explosion events that take place in an elevator facility.

5. Examine known information on explosion phenomenon of grain dust and seek and identify additional or missing data.

B. Evaluation of Fire or Explosion Hazards for Grain Elevators

Research is needed to properly evaluate fire and explosion hazards for grain elevators. Often fire and explosion hazards have been determined on the basis that a condition, operation, or type of mechanical or electrical device might cause an unsafe condition in grain elevators. These hazard determinations may be made without specific or technical knowledge on the recommended or identified hazard contribution, if any, to an explosion or fire. Hazards should be identified on a scientifically sound basis and not on opinion or theory.

Identified Research Projects in Order of Priority

6. Study static charging of dust particles and ignition from static discharges. Static sources present in grain elevators should be measured and analyzed to properly evaluate hazards from static discharges. Research should consider and answer the following questions: (a) What is the likelihood of static discharges occurring at a point which is sufficient to act as an explosion ignition source? (b) To what extentent should static grounding techniques be utilized in grain elevators? (c) What is the contribution, if any, of the different types of equipment and the relationship if any, of the equipment and the close proximity of grounding points that occur in elevators and equipment? (d) What are the relationships to static discharge energies and dust ignition temperatures to the possibility of sufficient energy occurring from a a static discharge to ignite grain dust?

7. Determine the degree of concern needed for metallic or non-metallic sparks containing a sufficient energy to act as an ignition source. Sparks which occur from machinery, tramp metals or hobnail boots should be evaluated to determine the hazard involved, if any.

8. Study the development of a scientific basis for classifying hazardous areas of grain elevators due to the presence of dust. Present hazard classifications are

based on standards established for a number of industries. More pertinent elevator dust hazard classifications are needed to remove subjective judgments.

9. Determine the degree of hazard from the presence of a dust film on electrical or mechanical equipment and facility structures in grain elevators.

10. Examine the relationship of dust accumulations to fire or explosion hazards in grain elevators.

C. Assessment of Available or New Technology to Reduce the Potential of Grain Elevator Fires and Explosions

Research is needed to determine available or new technologies that are related to determined causes and can be identified to help reduce the potential for an elevator fire or explosion. Such investigations should consider the following items: (1) identification and availability of new or existing technology to reduce the potential for elevator fires and explosions, (2) the technical feasibility of applying the identified technology to grain elevators, and (3) the cost of the technology and its economic feasibility for utilization in the industry.

Various technologies have been suggested to assist in avoiding or reducing the potential of fires and explosions. Limited research is available to assess the feasibility of using suggested technologies for fire and explosion detection, prevention or minimization in grain elevators.

Additionally, there is a need to investigate the development of new technology to reduce fire and explosion potential. This becomes critically important since many elevator explosions are of undetermined cause. There is a need to improve investigative techniques to identify the cause or causes of grain elevator explosions or fires. With more definitive causes investigated and determined for elevator explosions, new technologies could be developed to handle the newly discovered causes of explosions. Technologies to be assessed could include suggested changes in elevator handling operations, work practices or management techniques to avoid or lessen explosion or fire risks.

Identified Research Projects by Order of Priority

11. Investigate management control, work practices and grain handling technology either new or existing, that would reduce the potential of explosions and fires in grain elevators.

12. Research the development of early warning detection systems to identify explosive or hazardous conditions in grain elevators. Suggested early warning detection systems must be evaluated with a priority emphasis given to the examination of detection systems measuring temperature and heat in the elevator environment, and the presence of smoke or pre-combustion products. Other warning systems for elevator environments which may need evaluation are dust concentration and relative humidity detectors.

13. Research the utilization of explosion suppression systems in enclosed grain and dust handling euqipment for controlling an explosion before it reaches a hazardous or damaging level.

14. Determine whether the utilization of explosion venting panels and techniques minimize damage to elevators and reduce employee exposure to hazards. The scientific basis of explosive venting ratios established or recommended for use will need to be evaluated. Evaluation of explosive venting techniques and ratios will need to address the question of minimizing secondary explosions.

15. Investigate the use of water, oils, or other substances to minimize dust generation in handling grains.

16. Research the feasibility of using ionization to limit the amounts of dust in suspension in elevator spaces. Requirements of the National Electrical Code will need to be considered in evaluating this technology.

17. Examine the possibility of using additive materials to raise the minimum explosive limit of grain dust beyond an ignition source's energy level.

18. Examine the feasibility of using inert gases inside grain elevator electrical control panels to minimize explosions and fires by limiting electrical ignition sources in elevator facilities and machinery. The economic feasibility of using inert gas atmospheres in elevator handling equipment and facilities is considered questionable.

D. Grain Dust Characteristics

The scope and complexity of research projects in this area of investigation will require the involvement of professionals from several scientific disciplines. Analysis of grain dust characteristics will require laboratory analysis. Because of scope and required scientific measurements, assistance and support from governmental agencies will be required. Industry assistance and cooperation will be vital to the performance of research projects in this area of inquiry.

Limited research work has been done on explosion characteristics of agricultural dusts. The influence of grain dust particle sizes, which is of the greatest fire and explosion concern, needs investigation. Grain dust characteristics may vary throughout the grain handling system and the influence of this on the causes of fire and explosion needs investigation.

Preliminary information indicates that moisture levels in grain dust may be a factor for the explosibility of grain dust. The relationship of moisture levels of grain dust to explosibility should be investigated to determine its importance and whether there are any practical means to control dust moisture levels.

Research is needed to identify the best means to maintain grain dust concentrations well below explosive limits to reduce the potential of explosions or fires in elevator equipment or open spaces. Grain dust control technology has been utilized throughout the grain and feed industry to limit grain dust as a fuel source for explosions. Many questions have been raised concerning air pollution control usage and the incidence of fires and explosions in the grain and feed industry.

A research assessment of the possible relationship of air pollution control systems and grain elevator fires and explosions is needed. A better understanding of how grain dust collection systems can be utilized more efficiently will assist the industry and government in assuring that both the outside air quality and the environment inside of elevators is maintained to the degree economically and technically feasible.

Identified Research Projects by Order of Priority

19. Measure and document particle size distribution of grain dust in different portions of the elevator and in the handling system of the elevator. Particle sizes and dust characteristics vary according to different grains. Particle size and distribution is useful information to better understand grain dust concentrations and relationships to fires and explosions.

20. Evaluate chemical characteristics of various dusts found in grains. The dusts of different grains and dust of non-grain origins would be part of the analysis.

21. Examine the relationship between moisture in grain and the ignition level of dust aerosols; and the relationship between moisture in dust and the ignition level of dust aerosols.

22. Conduct research to determine ways to simplify maintenance and improve the reliability of dust control equipment. Maintenance is a persistent problem that plagues any industry in using complicated or technical machinery or devices.

23. Identify, examine and evaluate techniques that improve or assure grain dust entrainment and capture. This research may assist the industry by optimizing standard collection hood designs and help eliminate the need for custom design of dust collection hoods and enclosures.

24. Conduct research to investigate the effects of air pollution regulations as a contributing factor, if any, to the incidence of elevator fires and explosions.

25. Assess the need for air pollution controls on grain elevators and the protection afforded to the general public's health and welfare. A questions of central concern is: Are control techniques other than fabric filter control systems sufficient in providing protection of public health and welfare?

II. Research Projects and Activities to be Conducted by Industry

Industry associations and members have the unique capability of conducting research to better understand the causes, nature and means to prevent explosions and fires. The National Grain and Feed Association identified four major areas of industry research. These four areas complement research recommendations presented to government. The four industry research areas follow in order of priority (A-D).

A. Designing Grain Elevators to Reduce the Potential of Explosions and Fires

The grain and feed industry is concerned about grain elevator design and physical plant layout and will evaluate changes needed in this area. A project of this scope would investigate measures to reduce the potential for fires and explosions; to minimize the exposure of employees and others performing work at grain elevators to risks of fires and explosions; and to minimize property damage resulting from a fire or explosion.

An investigation of elevator design is well within the capabilities of the industry and would involve those most knowledgeable of elevators and equipment utilized by the grain marketing system. The evaluation and information about best designs currently available and new design ideas would be useful in planning new elevator facilities or modification of existing facilities. Additional benefits of design research would be identification of equipment, processes and designs which assist in reducing grain breakage and maintaining grain quality. Thus, the design of elevators should be a high priority concern for the grain and feed industry to investigate.

B. Assessment of the Statistical Relationships and Significance Between Environmental Factors and the Occurrence of Grain Elevator Explosions

It would be useful to elevator owners and operators to understand whether or not certain climatic and operating conditions increase the potential for grain dust explosions. Statistical significance of the relationships studied would assist industry and government officials in establishing procedures to reduce the potential of grain dust explosions.

Many questions are raised when explosions occur, especially when a number of explosions occur over a relatively short time period. A statistical evaluation is needed of the incidence of elevator explosions. The documentation on grain dust explosions indicates that 62% of the reasons for the explosions are unknown. The researchers will need to extensively search public records and weather data. The researchers may need to identify changing technology of elevator operations in the industry. Factors such as weather, amount of grain being handled and automation of elevator operations may be some of the factors which may be related to elevator explosions.

C. Measurement of the Variability of Environmental Conditions Inside Grain Elevators and Storage Facilities and Machinery

Many variables need to be taken into account when determining whether or not environmental conditions in and outside of an elevator can be identified as hazardous and subsequent action taken to avoid or reduce the potential for a fire and explosion. In order to assess the impact of environmental effects upon incidence of elevator explosions and fires, there is a need for additional information. Characterization of internal elevator environment may assist the grain elevator industry in finding new ways to reduce the potential for fires and explosions. The study of grain dust concentration in elevator equipment and facilities will contribute to an understanding of hazardous internal environmental conditions. Research would help to assess the impact of atmospheric conditions and other internal environmental elevator conditions.

D. Evaluate Methods of Handling and Merchandising Grain Dust

The grain industry is reviewing and re-evaluating practices and procedure of collecting, handling and disposing and/or merchandising grain dust. The impact of these evaluations are of primary interest to the industry.

A cost and benefit analysis is necessary to evaluate methods of handling and merchandising grain dust. Factors in the analysis should include the quantity and quality of collected grain dust, the problems of handling grain dust, grain weight certification, the potential of fires and explosions, waste disposal, effects on marketing grain and monetary returns from merchandising grain dust. Industry management and marketing decisions would be facilitated by this research. Research findings would permit industry to maximize safety of employees and minimize business and property losses.

Appendix B

Background

The National Grain and Feed Association is a voluntary association of grain and feed firms ranging in size from the smallest country elevator to the largest grain and feed complex and includes not only country elevators, but inland terminal elevators, port terminal elevators, merchandisers, processors, warehousemen and exporters of a wide spectrum of grains and feeds. Its membership includes 1200 direct memberships by individual firms and 50 state or regional grain and feed associations affiliated with the National Association including approximately 12,000 grain and feed firms.

Subsequent to the four major grain elevator explosions which occurred in the last few days of 1977, the National Grain and Feed Association's president appointed a Management Team on Elevator Explosions and Fires to expand the association's activities in this critical area concerning both life and property loss. The purpose of the management team is: 1) to assess what is currently known about the causes of grain elevator fires and explosions, 2) to determine what additional information is needed and how it should be obtained and 3) to recommend guidelines for operational procedures based on best available knowledge to minimize the risk of fires and explosions. The first phase of the team's mission was to identify causes and determine management changes that might decrease the potential for fires and explosions. In this the management team looked at the known causes of elevator explosions. The second phase of the team's mission is to identify needed research and solutions to reduce the potential for explosions and fires.

Under phase one, the management team developed seven management guidelines for elevator operators to include in management's review of fire and explosion safety programs and policies. The National Grain and Feed Association transmitted these recommendations to its members to assist elevator management in implementing sound management practices to eliminate the known causes of grain elevator explosions.

Under phase two, the management team is recommending research projects and activities with the purpose of obtaining new information and understanding about grain dust characteristics and how to prevent and minimize grain elevator fires and explosions.

The National Grain and Feed Association recognizes the need for government and industry to conduct and support needed studies and research. In support of this, the National's Executive Committee unanimously passed the follwoing resolution:

"Whereas the Executive Committee of the National Grain and Feed Association fully recognizes the effects of the recent fires and explosions in the industry, and the Executive Committee deeply regrets that these disasters have caused loss of life, serious bodily injury, as well as substantial property loss, Now be it resolved that the Executive Committee of the National Grain and Feed Association commits our talents and our resources in an all out effort to find the causes of these disasters, working within the industry and with government agencies and other interested parties in order to avoid such occurrences in the future."

The National Grain and Feed Association and individual industry companies will be giving their attention to several other categories of research.

Robert M. Frye
Chief Engineer
FAR-MAR-CO, INC.

May 30, 1978

The FAR-MAR-CO Approach To The Prevention Of Grain Dust Explosions

Grain dust explosions are not a new phenomena to the grain industry. One of the first recorded explosions of grain dust occurred at a flour mill in Turin, Italy in 1783. Since then there have been numerous documented grain dust explosions. In the past few years, there has been an alarming increase in the number of grain elevator dust explosions and in the severity of these explosions. This climaxed with the explosions of Continental Grain and Farmers Export facilities which killed 52 persons in late December.

What are the reasons for these explosions, and is there a solution at hand?

Considerable technical and practical information has been gained from research conducted over the past century, and today the basic principles behind a grain dust explosion are well established. For a grain dust explosion to occur, three components must exist simultaneously.

1. Oxygen must be present above the minimum concentration permissible to cause ignition.
2. Grain dust must be in suspension between the lower and upper explosive limits of the explosive range.
3. There must be a source of ignition (spark, heat, or flame) having adequate energy to ignite the dust cloud.

For an explosion to occur, these criteria must be met within a confined volume; otherwise only a flash fire will result.

Other parameters which affect the explosibility of grain dust are the particle size and moisture content of the grain dust. If any leg of this triangle is removed, an explosion cannot occur. Therefore we must look very carefully at every leg of this triangle.

It is not feasible to remove the oxygen from a grain elevator, so consequently we have to deal with the remaining two legs of the triangle.

A number of different sources of ignition for dust explosions have been identified and are listed in numerous pieces of literature. Much has been done by the industry in recent years (and also as a result of insurance requirements) to eliminate many of these sources of ignition. As a practical matter however, all sources of ignition cannot be completely eliminated from a grain elevator. Some of these sources of ignition can be expected to be present during the normal working of a grain elevator, such as friction in moving parts, and the possible generation of static electricity. Others are more likely to be present during malfunction or mechanical or electrical breakdown. Another factor is the human element. No matter how much training an employee receives, there still exists the possibility that he may smoke a cigarette when no one is watching. As much as 85% of all sources of ignition has been attributed to human error of some sort. Therefore the exclusion of sources of ignition cannot be relied upon as the sole method of preventing a grain dust explosion.

Still, the grain industry has done a great deal in recent years to eliminate numerous sources of ignition and to educate the people working within these facilities. These factors should all help to minimize the likelihood of ignition sources being present in the grain elevator.

It seems logical that if there are fewer potential sources of ignition in todays elevator, there should be fewer grain dust explosions. What, then, are we doing today and in recent years that we weren't doing in years past to increase the potential for grain dust explosions?

For one thing, we are handling more grain which creates more dust. With modern dust control systems and the reduction in the sources of ignition, this would not account for the recent increase in the number of explosions.

This leads us to the third leg of the triangle which is the grain dust. What, then, are we doing differently with the grain dust today that we were not doing in years past?

With the advent of E.P.A., the use of fabric filters to meet various emission requirements has become more and more prevalent in elevators, especially at the terminal and export elevators.

The common practice in most of these facilities is to remove the dust at various points and then return it to the grain stream to maintain weight. What effect does this practice have on the grain dust? The following is a summary of FAR-MAR-CO Engineering test data which has been collected over the past three years.

Equipment

An explosion chamber was constructed which has inside dimensions of 12"x12"x18". The source of ignition was an electric coil. Twenty grams of dust were used in each test and were placed in suspension with a blast of compressed air at 70-80 P.S.I. There were 10 tests run on each sample and the chamber was cleaned by vacuum after each test.

A paper pressure relief vent with an opening 9½"x7" was used. All results were observed and recorded.

Sample #1

Location: Dust from fabric filter at
"Q" Elevator, Lincoln, Nebraska
Moisture: 9.0%

1. Exploded (violent)
2. Exploded
3. Exploded
4. Exploded (violent)
5. Exploded
6. Exploded
7. Exploded (violent)
8. Exploded
9. Exploded (violent)
10. Exploded

Sample #2

Location: Tailings from cyclone at
"Q" Elevator
Moisture: 11.0%

1. Exploded
2. Exploded (very slight ignition)
3. No Explosion
4. No Explosion
5. No Explosion
6. No Explosion
7. Exploded
8. Exploded (very slight ignition)
9. Exploded
10. No Explosion

Conclusions:

Although we feel that more and different types of tests are necessary, it appears at this point that the fine dust which has gone through a cyclone and fabric filter is more explosive and ignites easier than that which is returned to the grain stream from the bottom of the cyclones. The dust which is handled through a fabric filter is also dried somewhat, which will make it more explosive.

The following test was conducted in the same explosion chamber which was used for previous testing and the same procedures were used.

Sample #1 (20 grams used for each test)

Location: Dust from fabric filter at
Elevator "A", Hutchinson, Kansas
Moisture: 9.1%

1. Exploded (violent)
2. Exploded (violent)
3. Exploded (violent)
4. Exploded (violent)
5. Exploded (violent)
6. Exploded (violent)
7. Exploded (violent)
8. Exploded (violent)
9. Exploded (violent)
10. Exploded (violent)

Sample #2 (20 grams used for each test)

Location: Dust from cyclone at Elevator "A"
(has not gone through a fabric filter)
Moisture: 11.0%

1. Exploded
2. Exploded (very slight ignition)
3. Exploded
4. No Explosion
5. Exploded
6. Exploded
7. Exploded (violent)
8. Exploded (violent)
9. Exploded
10. Exploded

Sample #3 (20 grams used for each test)

Location: Dust from cyclone at Elevator "C", Hutchinson, Kansas
(has not gone through a fabric filter)
Moisture: 11.7%

1. Exploded
2. Exploded (very slight ignition)
3. Exploded
4. Exploded (very slight ignition)
5. No Explosion
6. No Explosion
7. Exploded (very slight ignition)
8. Exploded (violent)
9. Exploded
10. Exploded

Sample #4 (5 grams used for each test)

Location: Dust from fabric filter at
Topeka, Kansas Elevator
Moisture: 9.0%

1. Exploded (violent)
2. Exploded (violent)
3. Exploded (violent)
4. Exploded (violent)
5. Exploded (violent)
6. Exploded (violent)
7. Exploded (violent)
8. Exploded (violent)
9. Exploded (violent)
10. Exploded (violent)

Conclusions:

It appears that moisture content may be a very important part of the explosibility of grain dust. At this point it appears that grain dust at or below 10% moisture will explode 100% of the time when it is in suspension above the minimum concentration. This moisture range will probably include all dust which is collected in fabric filters.

The following is a summarized report of analytical data collected on elevator dust submitted by FAR-MAR-CO Engineering to Dr. Lyle Helmer with FAR-MAR-CO Research Division.

Date Received	Location Taken and Sample Identification	Moisture	Protein	Fat Ether Extract	Fiber %	Ash
4-10-75	Elev. B-Fabric Filter	8.0	7.8		23.4	10.4
7-18-75	St. Joe-Filter #1	5.6	10.8		7.4	39.4
10-6-75	Elev. B-Filter #1	7.2	10.1	1.6	17.3	14.9
10-6-75	Elev. B-Filter #6	7.1	9.4	1.5	18.4	14.2
11-24-75	Topeka-Filter #3	10.6	9.1	4.5	9.9	9.2
12-17-75	Topeka-Filter #1	8.4	10.8	2.0	10.5	10.9
1-21-76	Topeka-Dust Bin	10.3	7.7	4.1	12.0	13.6
1-21-76	Elev. A-Dust Bin	9.1	8.1	5.0	11.1	10.8
5-27-76	Elev. B-Dust Bin	8.6	12.7	1.6	17.8	11.1
6-17-76	Fairfax Elev.-Filter	6.3	22.1	4.12	4.4	18.3
6-9-76	Fremont Elev.-Dust Bin	8.9	10.8	1.2	13.1	8.8

Conclusions:

Composition of dust collected from different elevators varies quite noticeably. Variations could be due to differences in collecting equipment, types of grain being handled, and other factors. Variations can also be noted between dust samples from the same elevator.

The next test was conducted in the same explosion chamber which was used for previous testing and the same procedures were used. The purpose of these tests was to determine minimum explosive concentrations for grain dust of various particle sizes.

Tyler standard screens were used to divide grain dust according to micron size into three classes. Particles which are less than 63 microns (.0025 inches), particles which were between 63 microns and 125 microns (.0049 inches), and particles which were above 125 microns.

Sample #1 (less than 63 microns)

Location: Dust from Elevator A dust bin
(all dust from fabric filter)
Moisture: 9.1%

Ten tests were run on each sample.

Tried tests with 10 grams (100% exploded) (violent)
Tried tests with 5 grams (100% exploded) (violent)
Tried tests with 2½ grams (100% exploded) (violent)
Tried tests with 2 grams

1. Exploded (violent)
2. Exploded (violent)
3. No Explosion
4. Exploded (violent)
5. Exploded (violent)
6. No Explosion
7. No Explosion
8. Exploded (violent)
9. No Explosion
10. Exploded (violent)

Tried tests with 1½ grams (no explosion)
Tried tests with 1 gram (no explosion)

Sample #2 (greater than 63 microns and less than 125 microns)

Location: Dust from Elevator A dust bin
Moisture: 9.1%

Ten tests were run on each sample.

Tried tests with 15 grams (100% exploded)
Tried tests with 10 grams (90% exploded)
Tried tests with 7½ grams

1. No Explosion
2. No Explosion (burning around coil)
3. Exploded
4. Exploded
5. No Explosion (burning around coil)
6. No Explosion (burning around coil)
7. No Explosion
8. Exploded
9. No Explosion
10. No Explosion (burning around coil)

Tried tests with 5 grams (no explosion)

Sample #3 (greater than 125 microns)

Location: Dust from Elevator A dust bin
Moisture: 9.1%

Ten tests were run on each sample.

Tried tests with 5 grams (no explosion)
Tried tests with 10 grams (no explosion)
Tried tests with 15 grams (no explosion)
Tried tests with 20 grams

1. No Explosion
2. Exploded (very mild)
3. No Explosion
4. Exploded (very mild)
5. Exploded
6. No Explosion
7. Exploded (very mild)
8. No Explosion
9. No Explosion
10. Exploded (very mild)

Tried tests with 25 grams

1. No Explosion
2. Exploded (very mild)
3. Exploded (very mild)
4. No Explosion
5. No Explosion
6. Exploded
7. Exploded (very mild)
8. Exploded (very mild)
9. No Explosion
10. Exploded

Conclusions:

The minimum explosible concentration for dust which is less than 63 microns would appear to be between 47 grams/m3 and 35 grams/m3. At this time it would appear that 40 grams/m3 is about the minimum explosive concentration for grain dust which is taken from a fabric filter. The tests from the Bureau of Mines indicate that the minimum explosive concentration for mixed grain dust is 55 grams/m3. However, I suspect that the dust samples which they tested were not as high in % of wheat starch as ours were. This would help to account for the lower explosive concentrations found in the fine dust from Elevator A dust bin.

The particles in the 63-125 micron range required a much higher concentration and exploded much less violently. They were also more difficult to put in suspension and would not remain in suspension without some type of external assistance.

The particles above 125 microns were extremely difficult to ignite and did not appear to stay in suspension without external assistance. Although it is not clear what the exact effects of a mixture of these various sizes will have, it is apparent that the smaller and lighter particles are by far the most dangerous.

The following test was conducted in a new explosion chamber constructed by FAR-MAR-CO Engineering. It is identical to the previous chamber used except that the inside physical dimensions were changed to 12"x12"x24". This was to allow for the addition of a spark igniter which produces a 6000V spark at .020 Amps/sec. The spark igniter was placed in the explosion chamber in addition to the standard heating coil which we had previously used.

Sample #1 (5 grams)
(all particles less than 100 microns)

Location: Floor sweepings from Elevator B tunnel floor
Moisture: 13.7%

1. No Explosion
2. No Explosion (slight burning around coil)
3. No Explosion
4. No Explosion
5. No Explosion (slight burning around coil)
6. No Explosion (slight burning around coil)
7. No Explosion
8. No Explosion
9. No Explosion
10. No Explosion

Tried same dust w/10 grams
1. No Explosion (slight burning around coil)
2. No Explosion
3. Exploded (very slight ignition)
4. No Explosion
5. No Explosion

6. No Explosion (slight burning around coil)
7. No Explosion (slight burning around coil)
8. No Explosion
9. Exploded
10. No Explosion

Conclusions:

In the case of both explosions, the explosion was not immediate and the possibility exists that the particles were dried somewhat when placed in suspension in the explosion chamber due to the temperature and type of heating coil used to ignite the explosion. It would appear that grain dust at 13.7% moisture is extremely difficult to ignite and if it can be ignited, the explosion is much less violent than similar dust at a lower moisture content. The possibility still exists, however, that an initial explosion may cause some flash drying of dust in the 14% moisture range and that sufficient energy will be generated to cause a second explosion.

The subsequent test was conducted in our new explosion chamber which is 12"x12"x24". The purpose of this test was to determine if the fumigants used at FAR-MAR-CO have an effect on explosive concentrations.

For test purposes we selected Bin No. 544 at Elevator B in Hutchinson, Kansas.

This Bin contained wheat which was blended and placed in the bin on 7/6/76. The test weight was 61 lb/bu. and the moisture was 12.3%.

This grain was fumigated on 9/2/76, 11/16/76, and 12/9/77 with 80-20. It was fumigated on 3/30/77 and on 5/16/78 with Phostoxin. The dust samples were taken from the leg boot filter after the bags had been cleaned for a period of 1 hr and then Bin 544 was turned. This sample was taken and tested on 5/19/78. The dust from this bin and from a bin which had not been fumigated were both screened through a 63 micron screen as in previous tests. We were unable to detect any difference in minimum explosive concentrations between the two samples.

Conclusions:

At this point it does not appear that the fumigants which we are using play a role in the minimum explosive concentrations.

The results of these tests are very useful in evaluating the relative explosibility of grain dust at various moisture contents and of various particle sizes. However it should be noted that these values do not necessarily reflect absolute values which might be encountered in a grain elevator. Unlike gases, grain dust does not disperse spontaneously, but requires external stimulation such as air currents or mechanical stimulation. One thing is quite clear however, and that is grain dust is a very hazardous material if not properly controlled. It also appears clear that moisture content and particle size are the critical factors in the ignition sensitivity and forces generated by a dust explosion.

A greater understanding of the dust explosion mechanism can be attained by observing the frequency and force of explosions with grain dust which varies in particle size, moisture, and concentration.

Where then does this information lead? At FAR-MAR-CO, we feel it leads to the only logical conclusion for preventing a major grain dust explosion and limiting the severity of an explosion in the event of a localized explosion in a confined area such as a leg boot. That conclusion is to control and eliminate the third leg of the triangle - the grain dust. No matter what else may happen within a grain elevator, if the minimum explosive concentration of grain dust is not reached, an explosion will not occur.

The practice of removing dust via a dust collection system which takes the dust to a fabric filter and then returns it to the grain stream to maintain weight requirements is not only counter-productive, but it increases the concentration of smaller and lighter particles within the elevator. This type of dust control system also plays a significant role in drying the dust particles which in turn makes them more ignition sensitive. The increased concern about control of dust emission by various state agencies as mandated by E.P.A. has caused most terminal and export elevators and many country elevators to go to fabric filters in order to meet their emission requirements. With the return to the grain stream of the smaller and dryer dust particles, the potential for a major grain dust explosion is greatly increased. With more of the finer and drier particles within the elevator, a smaller amount of dust is required for a dust explosion than in years past. What was thought to be a clean and safe elevator 10 years ago may not necessarily be so today when judged by the same visual standards. In addition, the drier dust would require less ignition energy.

At FAR-MAR-CO, we feel this is the major factor in the increase in and severity of grain elevator explosions in the past three to four years.

What then is the answer to this obvious dilemma? The Federal Grain Inspection Service (FGIS) and various state grain inspection agencies are concerned over proper weights of grain. The removal of all grain dust collected in a properly designed dust system could pose a problem in accounting for proper weights.

At FAR-MAR-CO our answer to this problem has been and will continue to be a two-stage filtering system. The initial stage uses a cyclone or grain trap which removes the larger particles and returns them to the grain stream. The lighter and smaller dust particles are then passed to the second stage which is a fabric filter. This method removes almost all particles of less than 20 microns in size and most of the particles of less than 80 microns in size which are captured.

These smaller and drier particles from the fabric filter are then conveyed by a pneumatic conveying system to a dust bin away from the elevator and never returned to the elevator. The dust is then sold and used in various feed supplements.

By using this type of system, we have found that after the first four to six months (the time required to turn the grain once in one of our facilities) the % of shrinkage in this type of system is running 25 to 35 thousands of one percent. This is a very small amount but when considering the millions of bushels of grain handled at a large terminal or export facility, it can still be a very large amount of dust.

At the time of the writing of this paper, it is the author's understanding that the Federal Grain Inspection Service Advisory Board has recommended that all elevators wishing to do so be allowed to go to the same type of primary-secondary dust control system which FAR-MAR-CO is now using and that any shrinkage which would result as a result of this type of dust control system be called uncontrollable loss.

The use of a good, effective, properly designed and maintained dust control system which does not return the smaller and drier particles to the grain stream is the first step in the FAR-MAR-CO approach to minimizing the possibility of a major grain elevator explosion. While this is a very important step it is not the only step required to prevent an explosion. No dust control system, no matter how effective, can eliminate all grain dust from the elevator.

Therefore the second step is good housekeeping practices, and this cannot be stressed too strongly. Good housekeeping practices at all times can eliminate the possibility of a major dust explosion from occurring. Again I would emphasize that if there is not sufficient dust accumulations within a facility to reach the minimum explosive concentration, an explosion will not occur.

The third and, I feel, the most important step, is a total commitment by top management to provide safe facilities. At FAR-MAR-CO we have had this commitment from top management. We are now almost at the end of the fourth year of a six year program which involves major capital improvements to the dust control systems at all of our 16 terminal elevators. We currently have only one elevator where the dust collected in fabric filters is returned to the grain stream, and modification on that facility will be underway by the time of the presentation of this paper.

In addition to this financial commitment, top management made a commitment to all of our elevator superintendents to protect their lives and the lives of all employees working within that facility. Top management has given all of our superintendents the authority to shut down their facility at any time conditions are deemed unsafe, and that facility is to remain shut down until any such adverse conditions are corrected. This authority was given to the superintendents in the form of a written policy statement.

Some additional steps which are underway at our facilities to make them a better and safer place to work are as follows:

1. The slowing of conveyor belts and running of deeper bed depth of grain. This reduces the amount of dust which is created and liberated in the grain handling process.
2. The use of plastic buckets on all elevator legs.
3. The installation of motion sensors on all legs within our facilities.
4. The installation of explosion venting on all leg heads.
5. The use of self-extinguishing P.V.C. belts on all legs.
6. Investigation of several different methods of removing tramp metal from the grain stream.
7. Updating of all electrical equipment within our facilities which is not in compliance with the National Electrical Code.
8. Proper grounding including static bonding of all equipment within our facilities.

9. The painting of interior walls with masonry sealer and white paint. This aids in reducing possible dust accumulations, housekeeping, and improves lighting conditions.

10. The use of compressed air for cleaning in our facilities only when other methods are not adequate and only when the facility is shut down in the area being cleaned.

11. Providing lightning and voltage surge protection.

12. The use of heat sensors in all grain storage bins.

13. Daily inspection for start-up and shut-down of operations.

14. Machinery and equipment preventative maintenance programs which include complete record keeping.

15. Use of a written welding permit for both company employees and outside contractors. This in conjunction with shutting down of the facility and proper protection being taken.

16. Monthly safety meetings at all elevator facilities which includes training aids such as an explosion chamber and several slide presentations to help educate employees.

17. Development of a plant emergency organization (P.E.O.) including regular training programs.

18. Written shut-down procedures for choked legs.

Other advantages to this type of commitment are the following:

1. Better employee morale.

2. Less housekeeping required to keep elevator clean.

3. Reduction of electrical classification from Class II division I to Class II division II.

4. Better insurance rates. The insurance industry, through monetary incentives, can be one of the most effective means for making grain elevators safer.

5. The ability to comply with O.S.H.A. requirements.

In summary, FAR-MAR-CO feels that we have taken the only reasonable path available through current technology to prevent a major grain dust explosion within one of our facilities.

While we do not wish to force ideas on the grain industry, we take this symposium as an opportunity to present our research, thoughts, and ideas in the hopes that lives can be saved and with the sincere belief that major dust explosions such as Continental and Farmers Export can be prevented.

* * *

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BIN & TANK ENTRY
CUTTING & WELDING PERMIT No.

Effective: Date __________ Hour __________
Expires: Date __________ Hour __________
Permit Requested by: __________
of the __________ Section

Description of
Work to Be Done __________

Observations and
Special Precautions
Lock Out __________
(Signature)

Oxygen Test __________ %

Operator Informed __________
(Signature)

Permit approved, with the following exceptions: __________

__________ Safety Rep.
__________ Operating Supervisor

I certify that all precautions have been taken and will be maintained during the required period to the best of my ability.

__________ Date
__________ Hour
__________ Superintendent

Work Started:

Time __________

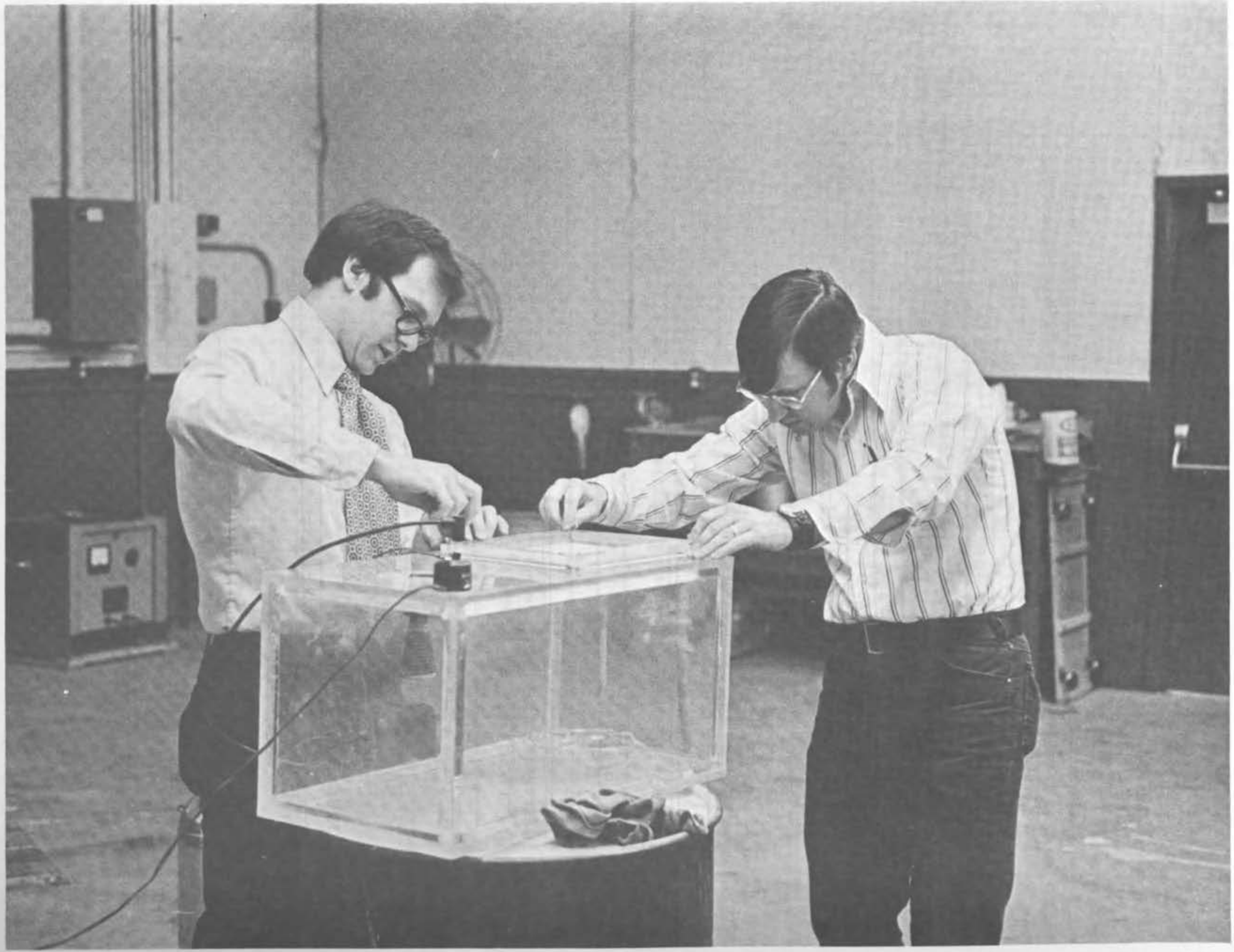
Mechanic in Charge __________

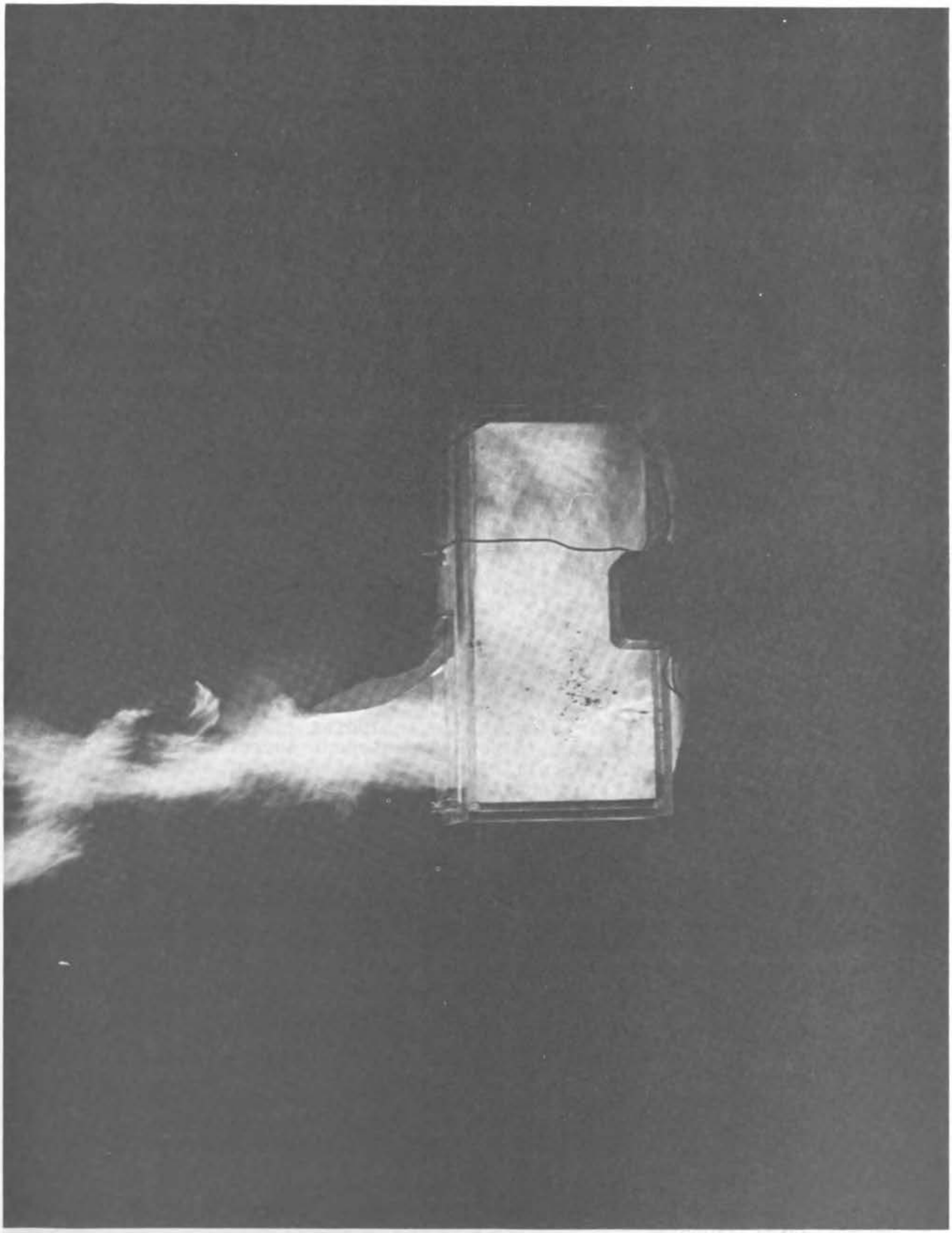
Work Completed:

Time __________

__________ Mechanic in Charge
__________ Superintendent

This entry to be retained for Supt.'s files.





FAR-MAR-CO
FAR·MAR·CO. INC. CORPORATE ENGINEERING

P.O. Box 1667 / Hutchinson, Kansas 67501 / Telephone 316-663-6861

CEA PROJECT DATA SHEET

CEA NO: 10037 PROJ. NO: ________ LOCATION: Saginaw, TX

NAME: Dust System PROJ. ENG: K.Hoover DATE 3-3-78

Gentlemen:

The following is our proposal for a modification to the existing dust control system for the new truck dump facilities located at Saginaw, Texas.

SCOPE OF PROPOSAL

Filter for new truck dump facility shall have suction on the following locations:
(1) Leg Boot
(1) Tunnel Belt
(1) Truck Sink, and
(2) Floor Sweeps

SYSTEM & EQUIPMENT SPECIFICATIONS FOR NEW TRUCK DUMP FACILITY

(1) Leg Boot (3,682 CFM)
(1) Tunnel Belt (4,260 CFM)
(1) Truck Sink (11,540 CFM)
(2) Floor Sweeps (1,100 CFM Ea.)

Total suction for the new truck dump facility is 19,482 CFM. The fan and duct work are sized for an operating velocity of 4,200 feet per minute.

Complete mechanical installation including equipment installation and all ducting, hoods, elbows & equipment supports. Also included in the mechanical installation is the patching of existing openings for which the ducting shall run through.

New dust filter to be complete with air to cloth ratio of 8.9 to 1. Suction for this system will be supplied with a Class 4 fan complete with 60 horsepower TEFC motor.

This system will also include a 3" pneumatic system to take the dust from the filter and discharge it into the dust storage bin. All installation work is based on the use of union labor. All materials and workmanship to be in accordance with FAR-MAR-CO, INC. dust system specifications and drawings.

ELECTRICAL WORK

Electrical work to be complete per FAR-MAR-CO, INC. dust system electrical specifications and drawings.

This system shall remove the dust from the elevator via the filter system and convey it to the dust bin for disposal.

This approach removes the "nuisance" dust which is the primary cause of explosive concentrations and eye, nose and lung irritation. This system will also reduce the possibility of a major explosion.

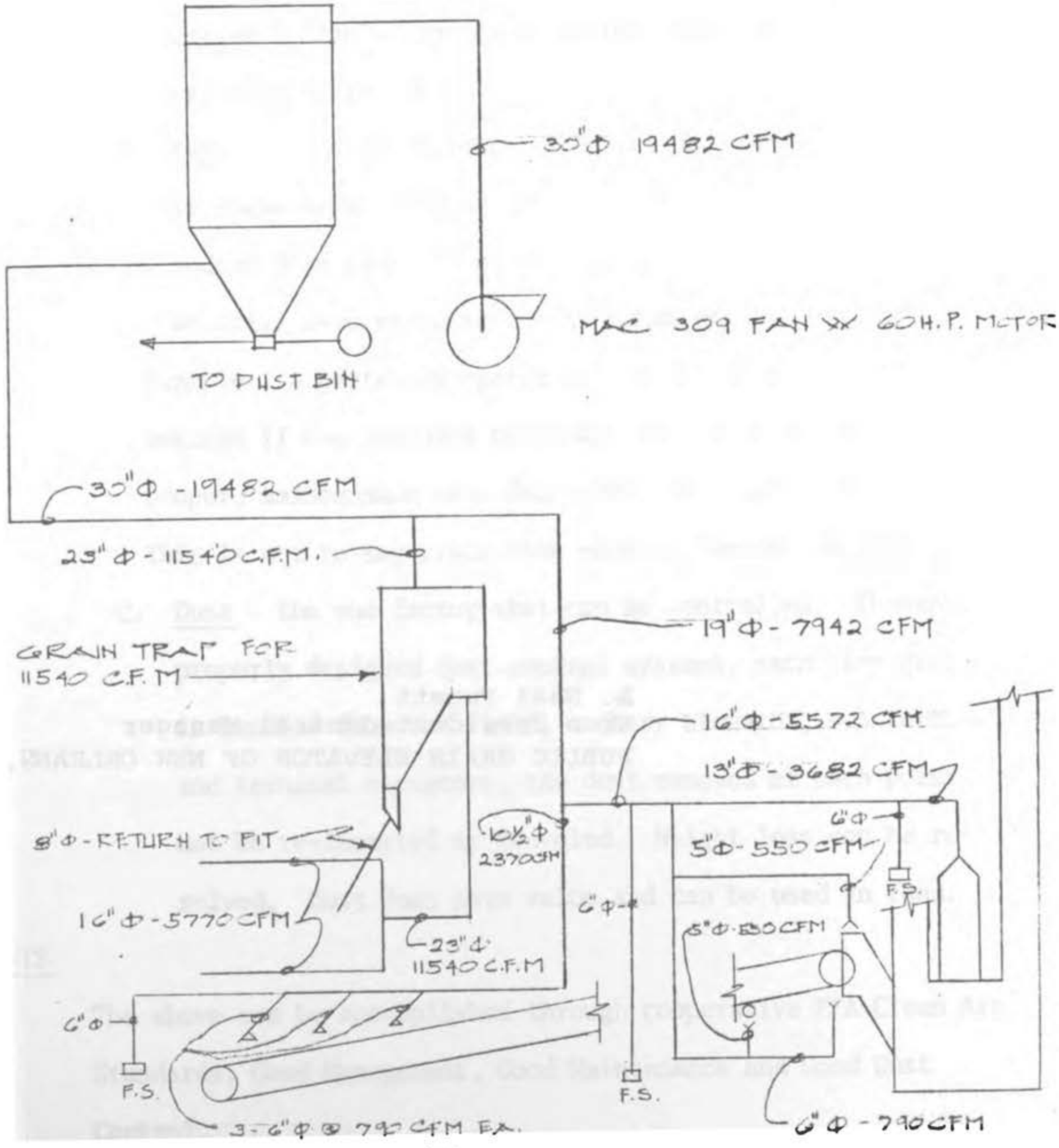
FAR-MAR-CO. INC. CORPORATE ENGINEERING
P.O. Box 1667 / Hutchinson, Kansas 67501 / Telephone 316-663-6861

CEA PROJECT DATA SHEET

CEA No. 10037 PROJ. No. ________ LOCATION FT. WORTH

NAME: NEW PIT PROJ. ENG. K. HOOVER DATE 3-3-78

MAC FILTER MODEL 144 MW 108 W
AIR TO CLOTH RATIO OF 8.9-1



ELEVATOR EXPLOSIONS

A. Neal Fugett
Vice President-General Manager
PUBLIC GRAIN ELEVATOR OF NEW ORLEANS, INC.

ELEVATOR EXPLOSIONS

CAUSE

Proper combination of Dust - Oxygen - Ignition.

SAFEGUARD

Removal of any one of the three causes.

A. Oxygen - Highly improbable if not impossible in existing facilities.

B. Ignition - also improbable, if not impossible, even if every known rule or code of fire protection, every modern detecting and preventative device were used, we still have to contend with human error.

Example: A perfectly operating slowspeed switch is useless if the operator overrides it. Lack of, or improper, maintenance also falls into this human factor. This is not to say protection devices are not necessary.

C. Dust - the one factor that can be controlled. Through properly designed dust control systems, each time grain is handled from the field, country elevator, sub-terminal and terminal elevators, the dust removed at each point not be re-inserted or recycled. Weight loss can be resolved. Dust does have value and can be used in feed.

COMMENTS

The above can be accomplished through cooperative EPA Clean Air Standards, Good Management, Good Maintenance and Good Dust Control.

EPA

More reasonable standards allowing present facilities with properly operating cyclones, 90-95% efficient, to discharge the fines into the atmosphere.

MANAGEMENT

From the top down, when figuring an elevator's handling capacity, maintenance be considered first before arriving at any daily or monthly average. Insist all outside contractors comply with the same safety proceedures as the elevator employees.

Education of all employees in the proper operation of all the systems. Firm rules of operation: no elevator functions allowed when dust control system in need of attention, elevator buckets hitting casings, replacing leg belts before they come down, to mention a few. In this area, lower management is helpless if top management is placing production before safety.

MAINTENANCE

Constant and prompt attention to all leaks, misaligned belts, legs, rollers, especially automated facilities in areas seldom manned.

INTERNATIONAL SYMPOSIUM ON GRAIN ELEVATOR EXPLOSIONS

JULY 11, 12, 1978

INSURANCE INDUSTRY VIEWS

by

Leland J. Hall, Manager
Engineering Dept.
The Mill Mutuals

INSURANCE INDUSTRY'S VIEWS

Being in the insurance industry I assume that the first item that would be expected of us is to give some rundown of the number of explosions that have occurred in the past years. Most of the statistics that we have here were gleaned from the NFPA files.

DUST EXPLOSIONS
1900 - 1957

	TOTAL	GRAIN
Number	1085	490
Killed	640	381
Injured	1712	991
Damage $ million	100	70

DUST EXPLOSIONS IN GRAIN PLANTS
1958 - 1977

	TOTAL	1976	1977
Number	220	16	12
Killed	148	19	61
Injured	499	82	71
Damage $ million	148	47	46

It is my opinion that the present problem that we have regarding fire damage and explosions in grain handling plants began with the loss of the Bunge Elevator in Destrahan, Louisiana in September of 1970. It was at this time that the United States agreed to ship a large quantity of grain to Russia. Since that time we have been shipping a substantial volume of grain to other foreign countries and this has placed a heavy workload on our export and terminal elevators. For example, some of the losses that have occurred since that time are as follows:

PLANT	LOCATION	POSSIBLE CAUSE
Bunge	Destrahan, LA	Elevator leg choke
Goodpasture	Galena Park, TX	Possible leg fire
*Far-Mar-Co	Lincoln, NE	Slipping head pulley
Indiana Farm Bureau	Logansport, IN	Drive on conveyor belt from truck dump to elevator
Farmers Elevator	Galveston, TX	Ignited in tunnel between rail dump and elevator
Michigan Farm Bureau	Zilwaukee, MI	Welder
Kissner	Wayne City, IL	Unknown
Garvey Elevator	Chicago, IL	Lightning
International Multi Food	Duluth, MN	Welding (probable)
Continental Grain	Westwego, LA	Possible friction in leg
*Anderson Grain	Maumee, OH	Idler bearing on belt conveyor
Sioux City Terminal	Sioux City, IA	Unknown
Indiana Farm Bureau	Kokomo, IN	V-belt drive
Tabor Grain	N. Kansas City	Unknown

We would point out some difficulties in design in the two losses noted by asterisks. It is our understanding in the Far-Mar-Co loss in Lincoln, Nebraska that one of the employees jogged the elevator leg to free a choke. Evidently the choke was severe and this resulted in the slipping of the head pulley. What we would like to point out in this particular loss is that to remove dust from the elevator leg, suction was taken at the head pulley in lieu of the boot. While I am certain that the desirability of taking dust from the head as opposed to the boot can be argued by various sources, however, by removing dust at the head and having the head pulley slip as it did in this particular case, we have created an excellent means of providing an adequate air supply to increase the intensity of the fire and result in an ultimate explosion as it did. It is for this reason that we recommend dust removal at the elevator boot.

With regard to the Anderson Grain loss in Maumee, Ohio, we have an excellent case of indicating how the size and magnitude of a loss can be reduced by the elimination of a gallery over the grain tanks. In this case the loss was limited to a section of the conveying unit over the tanks in lieu of possibly destroying an entire gallery, headhouse and possibly a number of grain tanks.

Thus it can be readily seen that from the aforementioned list of losses most of our problems are still basic, and much can be done to eliminate the losses without the assistance of additional research.

LOSSES CAUSED BY NEGLIGENT ACTS

A. Welding

We are certain that good welding practices are not followed by all operators. I believe every insurance carrier has put out some type of a welding procedure. For example. The Mill Manager or his appointee should inspect the proposed work area and check the cautions taken to prevent fire. We would recommend the following:

1. If sprinklers are provided, they should be in service.

2. Cutting and welding equipment should be in good repair.

3. Proper eye protection should be provided.

Precautions within 35 ft. of work -

4. Floors swept clean.

5. Combustible floors wet down, covered with damp sand or metal or asbestos sheets.

6. No combustible material or flammable liquids should be in the immediate area.

7. Combustibles and flammable liquids protected with asbestos tarpaulins or metal shields.

8. All walls and floor openings covered.

9. Asbestos tarpaulins suspended and beneath work to collect sparks.

10. Spouting, piping, etc. properly plugged.

Work on walls or ceilings -

11. Construction of area should be noncombustible and that which is combustible should be covered with an insulating material.

12. All other combustibles should be moved away from the welding area.

Work on equipment - (tanks, containers, ducts, dust collectors, etc.)

13. Equipment cleaned of all combustibles.

14. Containers purged of flammable liquid vapors.

15. Equipment in area shut down.

Fire Watch -

16. To be provided: during operation, for 30 minutes after operation, and every half hour for the next two hours (or longer if necessary).

17. Employees should be trained in use of equipment and in sounding alarm.

18. Final check at closing time.

The above should be considered minimal precautions taken when welding is done within the plant, and a permit should be issued by the plant manager prior to welding and signed by the person doing the work after the work has been completed, indicating all of the above had been done.

B. Smoking -

This is a practice that must be stopped in areas involving combustible dust. I believe the insurance industry in its entirety would recommend that any employee that is caught smoking within the plant be released.

C. Jogging of Elevator Legs -

This is a practice that should be discouraged and as a matter of fact one that should be stopped.

All of the three above hazards can be eliminated immediately if management is willing to adopt a hard-nosed philosophy in eliminating them.

MAINTENANCE

The following are items that cause losses because of poor or inadequate maintenance:

A. Slipping Head Pulleys -

This is a practice that can occur without the operator's knowledge. There are preventive measures that can be taken to reduce this type of loss.

1. Head pulleys should be lagged with a conductive lagging. Drive for the head pulley should be so sized that it will not overpower the unit, and overload relays should be provided so that in the event the unit is choked, the driving motor overload relays will trip. Protective measures that can be installed to assist the operator in eliminating slipping head pulleys are such features as an ammeter on the driving motor, or the installation of motion switches on the belt to indicate that the belt is operating at rated speed.

B. It is recommended that a routine practice be set up to determine the condition of all buckets on the elevator legs so as to eliminate the possibility of scraping of the cups against the leg housing.

C. Bearings on major units - It is recommended that heat detectors be installed on all main bearings. These units should function at a temperature between 180° and 200°F to note that the bearings are operating above rated temperatures.

D. It is recommended that either magnetic , gravity or pneumatic separators be installed. These units should be between the dump receiving grain and the elevator leg conveying the grain to the top of the plant.

E. The use of proper electrical equipment throughout the plant is essential. In other words, in Class II, Division 1 areas nothing but approved Class II, Group G equipment should be used. In areas involving Class II, Division 2 locations motors may be of the totally enclosed fan cooled type as long as they will operate at temperatures of 120°C or less under full load conditions. Motor controllers shall be of the NEMA Type 12 or dust tight type. All wiring, of course, should be installed in accordance with the National Electrical Code requirements. Portable lights should be of the type approved for Class II, Group G locations.

F. All hot metal working, exclusive of welding which has been noted previously, should be taken outside of the plant. In those instances where it is impossible to take this work outside of the plant the entire area should be cleaned and shut down as required in the case of welding.

G. Static electricity - All belts and conveying equipment used to move grain should be of the conductive type. Equipment used to support these belts should be bonded together and grounded to a common ground. It is also the opinion of the industry that much more research is necessary in the field of static electricity. We would recommend that this field be totally explored, advising as to the severity of damage that can be created by static electricity.

For the most part, the aforementioned items will eliminate the source of ignition within the elevator proper. To accomplish this a proper maintenance program is essential. From what we have been able to learn, very few plants have any type of preventive or operational maintenance program in effect. As a result it would be our recommendation that the plants consider putting into effect an operational maintenance system or a preventive maintenance system depending upon the complicity and size of operation.

OPERATIONAL MAINTENANCE SYSTEM

1. Operational Maintenance must be a planned part of the production effort. It cannot be secondary to other phases of production activity. Management must provide for:

    (a) Careful study and recording of lubrication, adjustment and "planned wear" requirements for each unit.

    (b) Establishing schedules and routes for operational maintenance procedures to maintain operational condition.

    (c) Assigning maintenance responsibility to trained employees.

    (d) Follow-up in the form of lubrication records, spot checks, breakdown and bearing failure analysis and other devices to insure an effective operational maintenance system.

2. The system must allow for continuity in case of employee absence or replacement due to sickness or promotion.

3. Lubrication.

    (a) Establish lubrication requirements. Consult the manufacturer's handbook for the lubrication requirements of bearings.

    It is suggested that a card file be established for each device requiring lubrication. This should list the type of lubricant and frequency of application. If the bearing should be flushed or purged, this frequency should also be included. This card file must be kept current when changes are made in the lubrication procedure.

(b) Assign Responsibility.

When the proper schedules and procedures are established, the responsibility for lubrication must be assigned. Frequently, this will be the individual who supervises the operation of the equipment. A lubrication specialist, or specialists, may be designated for the plant. Adequate training should be provided as to type of lubricants, methods of application, amounts necessary, safety procedures and lubricant storage.

(c) Be Regular.

A route sheet (daily, weekly, etc.) can be developed showing when lubrication is necessary to satisfy bearing requirements. This will be the working part of the record system. Once the lubrication specialist is familiar with equipment requirements, he will not need to constantly refer to the detailed card file.

(d) Review

Proper follow-up is necessary to assure proper techniques and frequency. Adequate card file lubrication records allow checks to assure adherence to the predetermined schedule and proper technique. A study of bearing failure and replacement will indicate the quality of the lubrication program.

On larger systems we would recommend Preventive Maintenance Systems and they would be as follows:

PREVENTIVE MAINTENANCE SYSTEMS

1. The establishment of a Preventive Maintenance program can be justified by finding the cost of breakdown failure in repairs, down time, damaged stock, injuries, idle operators and additional overtime. Estimate the cost of repairs if they had been anticipated by inspection and corrected prior to breakdown-failure. The difference is what could be spent on Preventive Maintenance inspections.
2. Establishment of a Preventive Maintenance program should be treated as a plant investment. It will require resources to set up and some time to pay out.
3. Maintenance costs will probably be increased during the initial period of operation. A backlog of maintenance work will be disclosed by the Preventive Maintenance inspections. Inspection frequency cannot be established at an economically optimum level until experience records are analyzed.
4. Small plants should use a complete Preventive Maintenance system, but scaled down to the appropriate size of plant. They will devote the same percentage of maintenance effort to the Preventive Maintenance functions of clerks, supervisors and inspectors instead of full time specialists. They may also contract for specialized skills as electrical inspection work instead of training their own maintenance man. The need for Preventive Maintenance is often more critical in a small plant because failure of the one production line stops the entire production effort.
5. An essential part of a Preventive Maintenance system is the records. These careful records of equipment performance under a Preventive Maintenance system are necessary to tailor the inspection techniques to fit the equipment. Analysis of

the Preventive Maintenance program will indicate the necessity for improved inspection techniques, increased inspection frequency or conversely allow the relaxation of inspection rigor or frequency. By developing statistical information of previous breakdown failure, the need for replacement can be anticipated without inspection, or inspections can be timed to observe a deteriorating physical condition.

6. Under certain circumstances, Preventive Maintenance isn't justified. Where inspection is expensive relative to allowing ultimate failure, or where inspection techniques can't anticipate failure, Preventive Maintenance isn't appropriate.
7. The criteria for equipment items being included under Preventive Maintenance involves:
    - (a) Safety - Will failure jeopardize personnel or plant?
    - (b) Production Downtime - Will production capacity be seriously interrupted by breakdown failure?
    - (c) Product Quality - Will failure endanger product quality by contamination or commingling?
    - (d) Consequential Destruction - will extensive damage result from component failure?
    - (e) Large Capital Outlays - Will repairs need to be budgeted?
8. Determination of critical items to be included in the inspection program is made by joint consultation of production, maintenance and management personnel.

9. When the critical units are identified, the necessary inspection techniques are

reviewed. If inspection is unable to prevent failure or too expensive relative to failure, Preventive Maintenance isn't justified.

10. These are the necessary procedures of a Preventive Maintenance system.

    (a) Monitoring inspection schedules.

    The Preventive Maintenance inspections must be conducted on a regular basis. A file system is maintained of when the necessary inspections are due. This file system may be:

    (1) A calendar showing equipment and inspection dates.

    (2) A file date with a card placed in the day the inspection is to be required.

    (3) A file of all equipment which is checked each Preventive Maintenance inspection period.

    The individual monitoring the inspection schedule will notify the personnel responsible for conducting inspections.

    (b) Inspect and report results.

    The inspector will use a check list applicable to the unit of equipment being inspected. He will prepare a report form indicating the condition of the items checked. Frequently the check list and report form are combined.

    (c) Survey completed report and order repairs.

    When the inspection report is returned, items needing repairs are listed for attention under the regular maintenance procedure. A notation is made that the inspection was completed and what repairs were ordered or made.

    (d) Review.

    Periodic review of the Preventive Maintenance Program is necessary.

This can be done by examining the inspections scheduled versus those completed. A regular inspection progress report to management is advised. It is necessary to study the pattern of breakdowns to determine if Preventive Maintenance inspection procedures are effective. Total maintenance costs reflect the ultimate success or failure of the maintenance organization.

11. The record or paperwork part of the Preventive Maintenance program is absolutely essential. If short cuts are made at this point, it is probable that the entire Preventive Maintenance program will break down. The success of the Preventive Maintenance program will hinge on analysis of maintenance experience.

12. Unfortunately, there are no hard and fast rules to assist in establishing Preventive Maintenance systems. Standardized inspection frequencies and check lists do not exist. Preventive Maintenance systems must be established by individuals familiar with both Preventive Maintenance concepts and the actual plant conditions.

EVALUATING THE MAINTENANCE SYSTEM

1. A record should be kept of each instance where a breakdown occurred. The lost production time, breakdown description and necessary Corrective Maintenance should be recorded for analysis. The effectiveness of Preventive Maintenance procedures on that unit can be tested.
2. When the maintenance systems have been established, analysis should be made of division of maintenance time between repairs ordered from breakdown failure and repairs ordered from Preventive Maintenance inspections. A gradual adjustment

to stable levels will result. If breakdown failures do not decrease, the Preventive Maintenance system is not effective. If they go below an economic optimum, inspection procedures may be too comprehensive and expensive. In either case adjustments must be made.

3. Maintenance employees are frequently involved in construction and alteration work. Their special skills and plant familiarity are essential. Regular maintenance work should not be allowed to slide during periods of construction work and proper scheduling is vital for efficient conduct of this work. Costs in payroll, materials or shop facilities incurred for this type of work should not be charged against the maintenance budget.

4. The entire purpose of the maintenance system is to reduce the cost of operation. Maintenance accomplishes this through improved equipment life and performance, reduced down time from breakdowns, better working conditions and improved safety. Good maintenance systems do this.

(SHEET A) EQUIPMENT HISTORY CARD EQUIPMENT	UNIT DEPARTMENT BUILDING
MODEL	FLOOR

MANUFACTURER		MECHANICAL
ELECTRICAL		
MAKE		
SERIAL		
VOLTAGE		CONTROL
PHASE	AMP	
HP	RPM	
DATE INSTALLED		

	LABOR	PARTS	TOTAL

(SHEET B) PREVENTIVE MAINTENANCE CALENDAR

EQUIPMENT	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
INSPECTIONS SCHEDULED												
INSPECTIONS COMPLETED												

(SHEET C) INSPECTION CHECK LIST AND REPORT FORM

UNIT

EQUIPMENT

DEPARTMENT

BUILDING

FLOOR

OK-GOOD CONDITION A-ACCEPTABLE BUT WORN R-REPAIR

CHECK LIST	OK	A	R	OK	A	R	OK	A	R	OK	A	R	OK	A	R	OK	A	R	OK	A	R
DATE																					
INSPECTOR																					

If a system of orderly maintenance is established, such as either of the aforementioned, we believe that a giant step will have been made toward the elimination of a source of ignition to occur in a grain handling or grain processing plant.

Inasmuch as the object of this particular symposium is to indicate those items that we feel are essential to eliminate or reduce the possibility of a severe loss due to fire or explosion in a grain handling plant, we believe not only is a good maintenance program essential eliminating the source of ignition but also we need to consider the removal of fuel. As noted early in this report we believe that our first real problem began in the 1970's when the terminal and export elevators began moving substantial amounts of grain to foreign countries. This resulted in plants being worked to capacity and in all probability in some cases in excess of capacity for long increments of time. We also have the problem of substantial demurrage charges due to the fact that not rail cars but trainloads might be delayed because of a breakdown in equipment and equally important in instances there could be cases where two and three ships were in port waiting for the elevator to load the ships. As a result, management naturally gave prime consideration to production.

In 1973 or 74 we added to this particular problem by some of the stringent rules set forth by EPA in bottling up the dust within the plant. Prior to this time, invariably elevators operated with open windows and open doors permitting the small or fine dust, that dust in the 2 or 3 micron to 20 micron size to blow out of the windows. This no longer being possible, the dust now is contained within the elevator and had to be removed by dust conveying methods. This resulted in some systems being inadequately designed; having stocking collectors too small for the amount of air that was being handled; having additional outlets placed on systems rendering the conveying systems inadequate. We also have the problem of inadequate maintenance on these systems and from time to time finding a portion of the system in disrepair. All of this has added to our dust problem within the elevator. As a result we would make the following comments regarding the elimination of the source of fuel within the grain elevator. Practices that we would recommend in this area are as follows:

A. The weighing and grading standards should be such that they permit complete and continuous removal of all fine dust (40 micron and less). It is also recommended that this dust be conveyed to a bin remote from the plant proper.

B. A complete dust control system (s) capable of maintaining adequate negative pressure in all enclosed components of stock handling systems such as elevator legs, distributors, bins, etc., and capable of capturing all dust at other emission points such as loaders, spouts, etc., so that explosive suspensions cannot exist in any part of the plant during normal operation.

C. Prior approval of dust control system plans by an Engineer <u>certified</u> in dust control design; licensing of installers.

D. That there be a mandatory regular inspection of dust control systems and their performance.

E. That there be mandatory both written and verbal instructions provided to operating personnel by design engineer or the installer. Too frequently systems are installed in plants by an installer and forgotten. Unless plant personnel are well versed in the operation of the systems, there will not be satisfactory operation of the dust control systems.

F. That there be an adoption of "automatic" features into dust control systems design to minimize human error (continuous tunnel conveyor hoods to eliminate need for manual operation of blast-gates, etc.,).

G. Differential gauges on filters, collectors should be accessible for mandatory daily reading and recording. All manometers to be clearly and permanently labelled with reading instructions.

H. Prohibition of dust recirculation - This no doubt will creat a great deal of discussion. However, with the advent of forcing all dust to remain in the plant, new problems have occurred. The dust that is collected, particularly through bag type collectors , is of a very fine type usually 10 microns and less and when permitted to re-enter the plant provides a hazard that has been creating some of our major explosions in the past few years. This dust of such a fine particle size and usually dried to a moisture content of some where between 10 and 6% is extremely hazardous. As noted previously this dust was permitted to be emitted or float out of the plant through open windows prior to the rules set forth by EPA. However, since it is now held within the plant and permitted or required to be recirculated back into the grain stream, we have created a major problem which must be stopped if we are to eliminate the explosions .

I. It is recommended that mandatory shutdown occur when any dust control system becomes dysfunctional. This is particularly true of systems that are collecting dust of particle sizes less than 40 microns.

J. All captured dust that is collected in cyclone collectors should be stored outside of the elevator proper.

We would recommend in this area that temperature, relative humidity and specific humidity be studied by adequate research so that this information can be made available to industry.

NEW CONSTRUCTION

In the area of new construction, we would definitely recommend elimination of confinement of the grain handling equipment.

Our first recommendation would be to consider the elimination of the headhouse in its entirety. In this particular case, it would be our recommendation that elevator legs that are used for moving the grain from the truck or rail dump into grain tanks be located outside. If this is accomplished, then explosion relief panels can be provided through the entire length of the elevator leg, making it possible to minimize any explosion that might occur within the elevator leg and, of course, eliminating the possibility of destroying the headhouse proper. There have been a number particularly country type elevators that have been using this type of operation with good success. Any equipment that was needed should be housed in a metal on metal building or enclosure with adequate explosion relief panels. If such is necessary it would be recommended that the size of the panels be predicated on a ratio not to exceed 1 sq. ft. for every 30 cu. ft. of volume.

Our next recommendation in this area would be to consider the elimination of the gallery section. In most of the present and older type elevators, the gallery is enclosed in a fire resistive concrete enclosure which again has been a means of transmitting the explosion throughout various sections of the plant.

We would also recommend consideration for opening up the tunnel area under the grain tanks. One procedure, particularly on elevators that are of a narrow type, would be to locate the conveying equipment externally of the bins proper. In those cases where it would be undesirable to do so, it is possible that the tanks supported on pilings, and the entire area under the tanks opened or again be provided with light metal enclosures so that in the event of an explosion occurring within this area it would not be confined and permitted to relieve itself without damage to the plant proper. Where underground tunnels are required for large steel grain tanks such as those holding 1/4,1/2 or 1-million bushel there should be adequate space between the tanks, so that in the event an explosion should occur because of an overheated bearing or someother failure, the tunnel could relieve itself without doing substantial damage to other tanks or equipment.

We would also recommend the elimination of inter bin venting. Where large number of tanks are involved in large complexes, small clusters of tanks could or should be vented into a common header and dust removed by an adequate dust control system in this manner.

In summation we would make the following comments, if we are to eliminate or at least reduce the possibility of explosions in grain elevators it is our opinion that the following recommendations must be complied with:

1. As noted previously, management must give safety priority over production; if not this then at least safety must be given the same consideration as production.

2. All dust of 40 micron size and less must not be returned to the elevator or to the grain stream as foreign material. This dust must be taken from the collectors and placed in a bin remotely removed from the elevator.

3. All dust in suspension in the plant must be removed by adequate dust control.

4. An adequate maintenance program must be instituted and maintained in operation if we are to eliminate the sources of ignition.

5. In new construction, reduce confinement by the following:
    a. Eliminate the headhouse or provide the headhouse with explosion relief. This must be in the ratio of at least 1 sq. ft. to every 30 cu. ft. of volume.
    b. Eliminate the gallery or provide it with explosion relief as noted in "a".
    c. Eliminate the tunnel or provide a means of explosion relief as noted in "a".

Lastly, we would recommend that research be done in the field of developing a dust concentration meter similar to the device used for measuring flammable vapor concentrations. Should such a unit be devised, it could aid materially in sensing when explosive mixtures were being attained and the entire plant could be shut down.

oo0oo

FUMIGATION

SUPERSEDES HANDBOOK PAGES 45-23 AND 45-24

SCOPE

This data sheet covers the fumigation of rooms, buildings, and other structural enclosures and the equipment within.

Fumigating operations carried out in specially designed chambers with appropriate storage and handling systems are fairly safe. (See appropriate Factory Mutual loss prevention data sheets on pressure vessels and on the handling and piping of flammable liquids and gases.)

Fumigation with ethylene oxide presents special hazards which are covered in Data Sheet 7-82.

GENERAL

Fumigants are materials which are used in the gas or vapor phase to destroy harmful vermin, insects and their larvae, bacteria, viruses, weeds, fungi, and other living organisms. Pesticides, rodenticides, insecticides, fungicides, etc. are often applied as fumigants.

It is frequently necessary to fumigate flour mills, grain elevators, and other buildings or rooms containing food, tobacco, natural fibers, or furs.

Nearly every fumigation operation introduces or increases the fire hazard. Many fumigants are flammable, or are mixed with flammable solvents or carriers. Moreover, their toxicity prevents or hinders effective manual fire fighting.

Sometimes fumigation of entire buildings or even groups of buildings at the same time is required. It may be hours before these areas can be safely entered once fumigation is started. These large scale operations can expose the property to a large loss unless adequate precautions are taken.

CONTROL OF FUMIGANTS AND FUMIGATION

Fumigants and fumigation are normally controlled by governmental agencies. In the United States, these materials and procedures are under the jurisdiction of the Environmental Protection Agency (EPA) and various state agencies. Fumigants, pesticides, and similar materials must be registered with the EPA for "general" or "restricted" use. Some materials are prohibited. Persons using restricted materials must be certified. *Private Applicator* certificates are issued to owners or employees of the property involved. *Commercial Applicators* certificates are issued to people who can qualify to handle these materials on the property of others.

In the United States, there are some 34,000 registered formulations made from one or more of some 900 chemical compounds.

Fire and explosion hazards of most of these chemicals can be found in Loss Prevention Data Sheets 7-19N, 7-23S, and 7-23N.

FUMIGATING EQUIPMENT

Portable and fixed equipment are available for applying fumigants as a spray or dense fog. Petroleum distillate serves as the insecticide or as the vehicle for other insecticides or active ingredients. Atomization is often achieved by compressed air connected to dispensing units or guns.

Automatic equipment is preferable to manual equipment. Controls on this equipment can be preset to start the spraying at a given time and at a predetermined discharge rate, and to shut down the equipment automatically when treatment is completed or if a pressure temperature, flow, or other malfunction occurs.

Units called thermal foggers are available. These units atomize the fumigant by hot gases generated by a self-contained burner. Gasoline or propane is the normal fuel. These units are ignition sources and their use indoors should be restricted to an area of low combustible content and construction.

HEAT AS A FUMIGANT

Buildings infested with insects or fungi are sometimes heated to about 130° F (55°C) for about 24 hr. Where practical, this process is preferable to the use of flammable and poisonous fumigants. Generally, watch service can be continued during the process.

ILLUSTRATIVE LOSSES

1. An employee at food processing plant was using a thermal fogger when a malfunction enveloped the gun barrel in flame. The employee pushed the unit onto a loading dock, but it rolled off the dock and the gasoline tank rup-

tured. One sprinkler head in the dock operated. Although the unit was destroyed, the building damage was slight. (F-2420,1966)

2. Lightning struck a group of unsprinklered wood buildings used for blending, mixing, packaging, and storage of pesticides and herbicides including fumigants. Although the fire department responded within 5 minutes, they were hampered by toxic fumes. Approximately 5,000 nearby residents were evacuated for about 48 hours. The loss exceeded $1.5 million. (AFF-260,1974)

3. A one-story sprinklered building used for the manufacturing of prepared cookie and biscuit dough was being fumigated by a two-step process. Methyl bromide was released from two points within the building. A few minutes later, hydrogen cyanide, a flammable gas, was introduced from a cylinder located outdoors through a system of rubber hoses with 21 nozzles distributed throughout the building. Three quarters of an hour later, compressed air was blown through the hoses to clear them of liquid. Five minutes after this, an explosion occurred and the sprinkler alarm sounded. It was almost 1 hour before the building could be entered by personnel wearing masks, and 5 hours before it was completely cleared of toxic fumes. Roofing on about two thirds of the building had lifted and about the same area of the ceiling was charred or blackened. Stock and equipment was wetted by 87 sprinklers. Supposedly, all gas and electric service had been turned off before starting the fumigation. The ignition source was not determined. Improper mixing of methyl bromide and hydrogen cyanide allowed an explosive mixture to form. The gases should have been premixed outside the room. The loss was approximately $25,000.(X-6, 1960)

SAFEGUARDS

Large-scale fumigating operations call for following safeguards:

1. Have portable extinguishers, fire hose, and gas masks readily available. Make certain that automatic sprinkler systems are in service.

2. Clean the area thoroughly and remove any oily rags, waste, or other unnecessary combustibles and highly reactive materials, especially oxidizers.

3. Eliminate all ignition sources, including open flames, unprotected lights, telephones, matches and smoking. Cut the main switch to the area to prevent operation of electrical equipment. If fans are necessary to the fumigating process, leave live only that part of the circuit supplying the fans and take precautions to prevent sparking.

4. Make certain that all windows, doors, and other openings to the area are closed. Post warning signs at all entrances, and take all necessary steps to prevent entry of unauthorized persons.

5. Provide continuous watch service around the area during fumigation period.

6. Notify the public fire department and plant emergency organization in advance of commencing operations.

7. Store fumigants out-of-doors or in a detached building, segregated from combustibles and other chemicals, where escaping flammable and poisonous gases will not be a serious hazard. Protect indoor storage with automatic sprinklers.

8. a. Where a flammable vehicle or carrier is needed, use a petroleum distillate having a minimum open-cup flashpoint of 175°F (79.4°C).

   b. Fumigating agents (active ingredients, formulations, mixtures etc.) that have a flashpoint below 175°F (79.4°C) should not be used unless they are premixed with inerts and applied in such a manner that formation of a flammable vapor-air mixture is avoided.

9. Operate the equipment in accordance with the manufacturer's instructions and only with the recommended fumigant.

10. Have a qualified person in continuous attendance while the equipment is operating.

11. Provide drip pans below atomizer units to confine any drippage caused by nozzle clogging.

12. a. Use thermal foggers only in areas of low combustible content or construction, never in areas containing low flashpoint liquids, combustible dusts, or large quantities of paper.

    b. Refuel, recharge, and start thermal foggers out-of-doors.

13. When heat is used as a fumigant:

    a. Replace ordinary sprinkler heads with intermediate temperature heads.

    b. Heating should be by steam or hot water, not direct open flame methods.

    c. Temperatures in the area should be checked frequently during the fumigation.

Note: Fumigation is covered in NFPA No. 57, *Standard for Fumigation*. There are no conflicts. NFPA No. 430, *Pesticides in Portable Containers* covers the storage of these materials. Except that Factory Mutual recommends automatic sprinkler protection for most storage, there are no conflicts.

September 1976
Supersedes December 1971

ELECTRICAL EQUIPMENT IN HAZARDOUS (CLASSIFIED) LOCATIONS

SCOPE

This data sheet discusses the classification of hazardous (classified) locations for electrical installations, and the types of electrical equipment that should be provided in Class I (flammable gases or vapors) and Class II (combustible dusts) hazardous locations.

This data sheet is intended to consolidate information on electrical equipment for Class I and Class II hazardous locations.

GENERAL

Selecting the proper types of electrical equipment for hazardous locations requires considerable judgment. Hazard severity must be correctly evaluated to assure safety and to avoid unnecessarily expensive installations. Electrical equipment specially suited to the location should be used to make the installation safe. For example, in locations where hazardous concentrations of flammable gases exist continuously, explosionproof, purged, or intrinsically safe equipment is needed.

Wherever possible, electrical equipment and wiring are the best located outside hazardous locations. For example, lights may be located outside a room, illuminating the inside through transparent panels. Motors may be located outside hazardous locations with properly sealed shafts extending into the hazardous location to drive mechanical equipment. Power equipment and control instruments may be located in remote, nonhazardous locations or in pressurized rooms which are suitable for general purpose equipment.

CLASSIFICATION OF HAZARDOUS LOCATIONS

The National Electrical Code and the Canadian Electrical Code divide hazardous locations into three "classes" according to the nature of the hazard: Class I, Class II, and Class III. The locations in each of these classes are further classified by "divisions" according to the degree of hazard. The following paragraphs define and describe the classes and divisions. (Class III locations involving combustible fibers or flyings in textile processes are covered in Data Sheet 7-1, *Textile Mills.*)

Class I Locations

Class I locations are those in which flammable gases or vapors are or may be present in air in quantities sufficient to produce ignitible mixtures. These locations often include processes where volatile flammable liquids are used. Volatile flammable liquids are those that have (a) a closed-cup flash point below 100°F (38°C) or (b) a closed-cup flash point of 100°F (38°C) and above if heated higher than their flash point.

Class I, Division 1 locations are locations: (1) in which hazardous concentrations of flammable gases or vapors exist continuously, intermittently, or periodically under normal operating conditions; (2) in which hazardous concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or leakage; or (3) in which breakdown of equipment might release hazardous concentrations of flammable gases or vapors, and might cause simultaneous failure of electrical equipment.

In many instances, this Division 1 classification applies only to part of a building or room. Each room, section, or other area should be considered individually. Under normal operating conditions, sufficient mechanical ventilation is often provided to eliminate the possibility of an ignitible mixture. The flammable vapor concentration is usually maintained at less than 25% of the lower explosive limit by positive mechanical ventilation. In such uses (except those enumerated below or similar ones) the area is a Class I, Division 2 location.

The following are typical examples of Class I, Division 1 locations:

1. Unventilated pits, containing electrical equipment, in which volatile flammable liquids may accumulate.

2. Within 3 ft (0.91 m) of the fill opening of an indoor flammable liquid drum (even with adequate ventilation).

3. Locations under and adjacent to open kettles, mixers, or dip tanks (and their drainboards) containing volatile flammable liquids (even though room ventilation is positive and normally adequate).

4. The immediate vicinity of continuous cleaning operations where exposed volatile flammable liquids are used (even though room ventilation is positive and normally adequate).

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5. The immediate vicinity of open filter presses processing volatile flammable liquids (even though room ventilation is positive and normally adequate).

6. The immediate vicinity of normally closed equipment which is frequently opened and which contains volatile flammable liquids, or flammable vapors or gases (even though ventilation is positive and normally adequate).

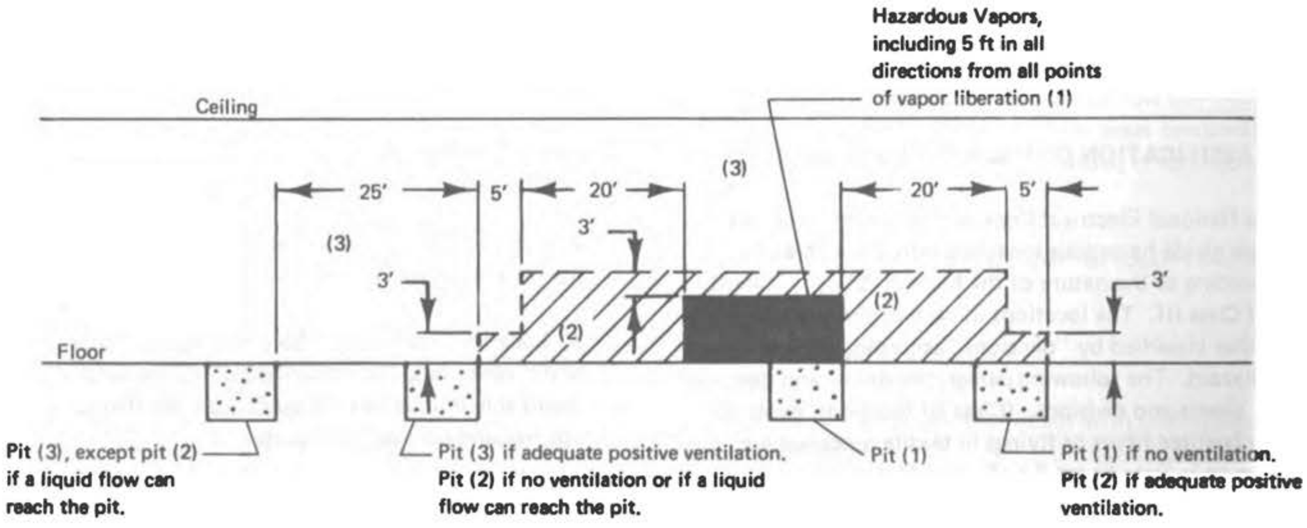
Class I, Division 2 locations are locations: (1) in which volatile flammable liquids or flammable gases are handled, processed or used, but in which the hazardous materials will normally be confined within closed containers or closed systems from which they can escape only in case of accidental rupture, breakdown, or abnormal operation; (2) in which hazardous concentrations of gases or vapors are normally prevented by positive mechanical ventilation, but which might become hazardous through failure or abnormal operation of the ventilating equipment; or (3) which are adjacent to Class I, Division 1 locations. Hazardous concentrations of gases or vapors might occasionally be communicated to these adjacent areas unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

To assist in the selection and location of equipment for Class I locations, Fig. 1 illustrates the degree of hazard at various distances from a typical vapor source. When applicable Factory Mutual standards (on specific distances) are available, reference should be made to them rather than to Fig. 1.

Class II Locations

Class II locations are those which are hazardous because combustible dusts are present.

Class II, Division 1 locations are locations: (1) in which combustible dust is or may be in suspension in the air continuously, intermittently, or periodically under normal operating conditions, in quantities sufficient to produce ignitible mixtures; (2) where mechanical failure or abnormal operation of equipment might cause such mixtures to be produced, and might also provide a source of ignition through simultaneous failure of equipment, or from other causes; or (3) in which combustible dusts of an electrically conducting nature may be present.



Hazardous Vapors, including 5 ft in all directions from all points of vapor liberation (1)

Pit (3), except pit (2) if a liquid flow can reach the pit.

Pit (3) if adequate positive ventilation. Pit (2) if no ventilation or if a liquid flow can reach the pit.

Pit (1)

Pit (1) if no ventilation. Pit (2) if adequate positive ventilation.

Fig. 1. Areas near indoor hazardous processes or equipment handling heavier than air vapors where special types of electrical equipment are needed.

Class II, Division 1 locations usually include the working areas of grain handling and storage plants; rooms containing such equipment as grinders, pulverizers, open conveyors, or similar dust producing machinery in plants processing grain, malt, starch, sugar, wood flour, or similar materials; starch-handling areas in candy plants; coal pulverizing plants (except where the pulverizing equipment is essentially dusttight); areas where metal dusts and powders are produced, handled, or stored (except in tight containers); and other similar locations where combustible dust may, under normal operating conditions, be present in the air in quantities sufficient to produce ignitible mixtures.

Class II, Division 2 locations are locations in which combustible dust will not normally be in suspension in the air, or will not be likely to be thrown into suspension in quantities sufficient to produce explosive mixtures by the normal operation of equipment. In these locations, (1) deposits or accumulations of combustible dust may be sufficient to interfere with the safe dissipation of heat from electrical apparatus; or (2) deposits or accumulations of combustible dust on, in, or in the vicinity of electrical equipment might be ignited by arcs, sparks, or burning material from such equipment.

Class II, Division 2 locations usually include those containing only closed conveyors, closed bins, or machines from which appreciable quantities of dust would escape under abnormal operating conditions; rooms adjacent to Class II, Division 1 locations into which ignitible concentrations of suspended dust might be communicated only under abnormal operating conditions; rooms where ignitible concentrations of suspended dust are normally prevented by effective dust control equipment; or warehouses and shipping rooms where dust producing materials are stored or handled only in bags or other containers.

Group Classification

For purposes of testing and approving electrical equipment, atmospheric mixtures are classified in seven groups (A through G) depending on the kind of material involved.

Groups A through D consist of flammable gases or vapors. They are classified according to (1) their ability to propagate flame through a flanged joint, (2) their ignition temperatures, and (3) in some cases, their ignition energies.

Group A. Atmospheres containing acetylene.

Group B. Atmospheres containing butadiene, ethylene oxide, hydrogen, manufactured gases containing more than 30% hydrogen by volume, or propylene oxide.

Group C. Atmospheres containing acetyaldehyde, cyclopropane, diethyl ether, ethylene or unsymmetrical dimethyl hydrazine.

Group D. Atmospheres containing acetone, acrylonitrile, ammonia, benzene, butane, 1-butanol, 2-butanol, n-butyl acetate, isobutyl acetate, ethane, ethanol, ethyl acetate, ethylene dichloride, gasoline, heptanes, hexanes, isoprene, methane (natural gas), methanol, 3-methyl-1-butanol, methyl ethyl ketone, methyl isobutyl ketone, 2-methyl-1-propanol, 2-methyl-2-propanol, petroleum naphtha, octanes, pentanes, 1-pentanol, propane, 1-propanol, 2-propanol, propylene, styrene, toluene, vinyl acetate, vinyl chloride, or xylenes.

Groups E through G consist of combustible dusts. They are classified according to (1) their ability to penetrate joints, (2) their blanketing effect, (3) their ignition temperatures, and (4) their electrical conductivity.

Group E. Atmospheres containing metal dust, including aluminum, magnesium, or their commercial alloys, or other metals of similarly hazardous characteristics.

Group F. Atmospheres containing carbon black, charcoal, coal or coke dusts which have more than 8 percent total volatile material. (Carbon black according to ASTM D1620; charcoal, coal and coke dusts according to ASTM D271). Atmospheres containing these dusts with less than 8 percent total volatile material but sensitized by other materials enough to present an explosion hazard are also included in this group.

Group G. Atmospheres containing grain, flour, or starch dust.

METHODS OF PROTECTION

Various methods are available to protect electrical equipment used in Class I and Class II hazardous locations.

Explosionproof and Dust-Ignitionproof Equipment

Explosionproof electrical equipment is suitable for use in Class I hazardous locations. The term *explosionproof* means that the device has an enclosure which is capable of withstanding an internal explosion of a specified gas or vapor without igniting a similar external mixture. Also maximum external surface temperatures are below the ignition temperature of the materials to which the enclosure may be exposed.

Dust-ignitionproof electrical equipment is suitable for use in Class II hazardous locations. The term *dust-ignitionproof* means that the device has an enclosure which will exclude ignitible amounts of dust. Also the enclosure will not permit arcs, sparks, or heat generated inside the enclosure to ignite exterior accumulations of dust.

Purged Enclosures for Equipment in Class I Hazardous Locations

Purging and pressurization of an enclosure or room is the supplying of air or inert gas (at sufficient flow and positive pressure) to reduce the concentration of any flammable gas or vapor to an acceptably safe level.

The three types of purging and pressurization generally used for electrical equipment enclosures are Types X, Y, and Z. Type X purging reduces the classification within an enclosure from Class I, Division 1 to nonhazardous. Type Y purging reduces the classification within an enclosure from Class I, Division 1 to Class I, Division 2. Type Z purging reduces the classification within an enclosure from Class I, Division 2 to nonhazardous. Purged and pressurized equipment, which is not approved, may be accepted if it meets the requirements of NFPA Standard No. 496, *Purged and Pressurized Enclosures for Electrical Equipment.*

For *Type Z purging of enclosures* with an internal volume not exceeding 10 ft^3 (0.283 m^3), a hazard is created only if the purge should fail at the same time the area which is normally nonhazardous becomes hazardous.

These Type Z purging systems should be designed as follows:

1. The enclosure should be purged if hazardous gases or vapors have collected in the enclosure.

2. Air of instrument quality or inert gas should be provided. Ordinary plant compressed air should not be used.

3. Power should not be turned on until at least four enclosure volumes of purge air or gas have passed through the enclosure. When the power is on, the enclosure should be maintained under positive pressure of not less than 0.1 in. of water column (24.9 Pa).

4. Under normal operation, the external enclosure temperature (or the temperature of the egress air) should not exceed 80 percent of the ignition temperature (°C) of the gas or vapor involved.

5. An alarm should be provided to indicate when the purging pressure or flow is inadequate to maintain a pressure of at least 0.1 in. of water column (24.9 Pa). The alarm signal should be in a constantly attended location.

6. A warning nameplate should be mounted on the enclosure. The nameplate should state that the enclosure should not be opened unless (a) the area is known to be nonhazardous, or (b) the power has been removed from the devices in the enclosure. The nameplate should also state that power should not be restored after the enclosure has been opened, until the enclosure has been purged.

7. The maximum operating temperature of any surface exposed to the atmosphere within the enclosure should not exceed 80 percent of the ignition temperature (°C) of the gas or vapor involved.

For *Type Y purging of enclosures* with an internal volume not exceeding 10 ft^3 (0.283 m^3), the electrical equipment in the enclosure must be suitable for Class I, Division 2 locations. Hence, a hazard is created in the enclosure only if failure of the purging system occurs simultaneously with failure of the internal equipment, producing a source of ignition.

These Type Y purging systems should be designed as follows:

1. The features indicated in Recommendations 1 to 7 for Type Z purging systems should be provided.

2. Make-and-break or sliding contacts should be (a) immersed in oil, (b) enclosed within a chamber hermetically sealed against the entrance of gases or vapors, or (c) in circuits which are incapable of releasing sufficient energy during normal operating conditions to ignite the specific atmosphere mixture involved.

For *Type X purging of enclosures* with an internal volume not exceeding 10 ft^3 (0.283 m^3), power must be removed from the equipment if the purging is interrupted in any way. This precaution is necessary because (a) a hazardous concentration of gas or vapor may exist external to the enclosure, and (b) the enclosure normally contains a source of ignition.

These Type X purging systems should be designed as follows:

1. The features indicated in Recommendations 1, 2, 6 and 7 for Type Z purging systems should be provided.

2. A timing device should be provided to prevent power from being applied until at least four enclosure volumes of purge air or gas have passed through the enclosure. The timing device should be suitable for use in Class I, Division 1 location of the Group (A, B, C, or D) of materials involved.

3. When the power is on, the enclosure should be maintained under a positive pressure of not less than 0.1 in. of water column (24.9 Pa.)

4. Upon failure of the purging system, a power-cutoff device should be provided to automatically remove power from all circuits in the enclosure. The cutoff device can be flow or pressure actuated. It should also be suitable for use in the specific Class I, Division 1 location involved.

For *purging of enclosures with an internal volume exceeding 10 ft^3 (0.283 m^3) and of rooms,* see NFPA Standard No. 496, *Purged and Pressurized Enclosures for Electrical Equipment.*

Pressurized Enclosures for Equipment in Class II Hazardous Locations

Pressurization of an enclosure is the supplying of air or inert gas with or without continuous flow at sufficient pressure to prevent the entrance of combustible dusts.

For *pressurized enclosures* with an internal volume not exceeding 10 ft^3 (0.283 m^3), a hazard is created in the enclosure only after the pressure has failed and ignitible amounts of dust have entered the enclosure.

These pressurized systems should be designed as follows:

1. The enclosure should be opened and the dust removed, if any combustible dusts have collected in the enclosure. The enclosure then can be pressurized.

2. Air of instrument quality or inert gas should be provided. Ordinary plant compressed air should not be used.

3. After the enclosure has been cleaned and pressurized, the equipment in the enclosure may be energized. The enclosure should then be maintained under a positive pressure of not less than (a) 0.1 in. of water column (24.9 Pa) if the particle density of the dust is 130 lb per ft^3 (2082 kg/m^3) or less, and (b) 0.5 in. of water column (124.4 Pa) if the particle density of the dust is greater than 130 lb per ft^3 (2082 kg/m^3).

4. Under normal operation, the external enclosure temperature (or the temperature of the egress air) should not exceed 80 percent of, and should be at least 50°C (122°F) below, the ignition temperature (°C) of the dust.

5. An alarm should be provided to indicate failure of the pressurizing system. The alarm signal should be in a constantly attended location.

6. A warning nameplate should be mounted on the enclosure. The nameplate should state that the enclosure should not be opened unless (a) the area is known to be nonhazardous, or (b) the power has been removed from the devices in the enclosure. The nameplate should also state that power should not be restored after the enclosure has been opened until combustible dusts have been removed and the enclosure repressurized.

Intrinsically Safe Electrical Equipment for Class I Hazardous Locations

Intrinsically safe equipment and wiring are incapable of releasing sufficient electrical or thermal energy under **normal or abnormal** conditions to ignite a specific hazardous atmospheric mixture in its most easily ignited concentration. Such intrinsically safe apparatus is suitable for use in Class I, Division 1 hazardous locations.

The National Electrical Code and Canadian Electrical Code recognize intrinsically safe electrical equipment and its wiring. The intrinsically safe apparatus is safe for use in the specified atmosphere without the special enclosures or physical protection that would otherwise be needed.

Industrial applications of intrinsically safe electric circuits are increasing considerably. There is a greater use of intrinsic safety to supplement or substitute for the other forms of protection in hazardous locations. Intrinsically safe equipment is ideal for process monitoring or controlling applications in chemical plants and petroleum refineries.

Intrinsically safe equipment must meet two special conditions. These are as follows:

1. The energy available in the hazardous location must

be incapable of igniting the specified fuel-air mixture under "normal" operating conditions. "Normal" conditions include operations at maximum line supply voltage and the environmental conditions which fall within the ratings given for the apparatus.

2. The energy available in the hazardous location must also be incapable of igniting the specified fuel-air mixture under "abnormal" operating conditions. "Abnormal" or fault conditions include operations with any combination of two independent mechanical or electrical faults occurring at the same time. If a defect or breakdown leads to defects or breakdowns in other components, the primary and subsequent failures are considered to be a single fault.

The required energy for ignition of any flammable gas or vapor mixture primarily depends on the flammable material, its concentration in air, its temperature and pressure just prior to ignition, and the prevailing electric circuit ignition characteristics. Each vapor-air mixture has a minimum value of energy that is required for ignition. Below this minimum, ignition of the mixture does not occur.

Electric spark ignition energy as applied to intrinsic safety may be expressed in joules or millijoules. In a capacitive circuit, energy = $W = \frac{1}{2} CV^2$. In an inductive circuit, $W = \frac{1}{2} LI^2$. W is the energy available in joules, C is the effective capacitance in farads, V is the capacitive voltage in volts, L is the effective inductance in henrys, and I is the inductive current in amperes.

Minimum ignition energies range from about 0.01 to 0.02 millijoules for acetylene and hydrogen; 0.2 millijoules for methane; and to over 100 millijoules for ammonia.

The ability of an electrical circuit or equipment to produce ignition is determined by the energy available and the manner in which such energy is released. The energy may be released by arcing (a spark), by high temperature, or by a combination of arcing and temperature. The energy released by an arc or spark discharge can be by (a) the discharge of a capacitive circuit, (b) the interruption of current in an inductive circuit, (c) the make-and-break of a resistive circuit, or (d) a combination of these three mechanisms.

Factory Mutual and other recognized laboratories examine electrical devices to determine, by analysis and/or actual tests, the ignition capability of the particular equipment. The laboratories determine whether or not the device is intrinsically safe for a specific hazardous location. Electrical equipment approved as intrinsically safe is listed in Factory Mutual's Approval Guide.

Intrinsically safe and associated equipment is designed and constructed by the manufacturer to limit the available energy to less than the required igniting energy for the specific flammable gas or vapor. A common way of limiting energy is by the proper selection of voltage, current, resistance, capacitance, and inductance in the equipment. Other considerations include the encapsulation of components, the use of an insulating barrier between windings of a transformer, the use of two properly insulated conductors separated by a barrier, and the conservative rating of components.

Non-Incendive Electrical Equipment For Class I Hazardous Locations

Non-incendive equipment and wiring are incapable of releasing sufficient electrical or thermal energy, during **normal** operating conditions, to ignite a specific hazardous atmosphere mixture. Such non-incendive equipment is safe for use in Class I, Division 2 hazardous locations. A special enclosure or other physical safeguard for the equipment is not needed.

Electrical equipment approved as non-incendive is listed in Factory Mutual's Approval Guide.

Intrinsically Safe and Non-Incendive Electrical Equipment for Class II Hazardous Locations

This type equipment is similar to intrinsically safe and non-incendive equipment for Class I locatons. However, effects of the dust on operability of the equipment has to be evaluated, in addition to ignition energy and temperature.

At present there are relatively few industrial applications of intrinsically safe and non-incendive electrical circuits for Class II hazardous locations. Indications are that this classification will have more use in the future. Approved equipment should be used wherever possible.

APPROVALS

Electrical equipment is approved for either Class I or Class II locations, or both, and for one or more atmossphere groups (A, B, C, D, E, F, or G) under each class. Surface temperatures of approved equipment do not exceed the ignition temperature of the specific gas, vapor, or dust for which the equipment is approved. It is marked to show the class, division, group, and operating temperature or temperature range for which it is approved. Electrical equipment can also be specifically approved and marked for Division 1 and 2 applications or for Division 2 only.

If available, Factory Mutual-approved equipment should be recommended. When FM-approved equipment is not available, equipment listed, labeled, or approved by another recognized testing laboratory is preferable to unapproved equipment.

EQUIPMENT FOR HAZARDOUS LOCATIONS

Where electrical equipment approved for Class I locations is recommended, it is the intent that the equipment used will be approved for the group which includes the specific hazardous material at the location and will be: (1) explosionproof; (2) purged and pressurized, designed to eliminate or reduce the hazardous concentration of flammable gas or vapor in the equipment; or (3) intrinsically safe.

Where electrical equipment approved for Class II locations is recommended, it is the intent that the equipment used will be approved for the group which includes the specific hazardous dust at the location and will be: (1) dust-ignitionproof; (2) purged and pressurized, designed to prevent the entrance of combustible dust into the equipment; or (3) intrinsically safe.

The kinds of electrical equipment recommended for locations containing flammable vapors as gases are shown in Table 1 and for locations containing combustible dusts in Table 2. Typical equipment is illustrated in Figures 2 and 3.

Fig. 2 Typical incandescent lighting fixtures for hazardous locations. Left, explosionproof. Center, enclosed gasketed. (See Table 1.) Right, dust-ignitionproof.

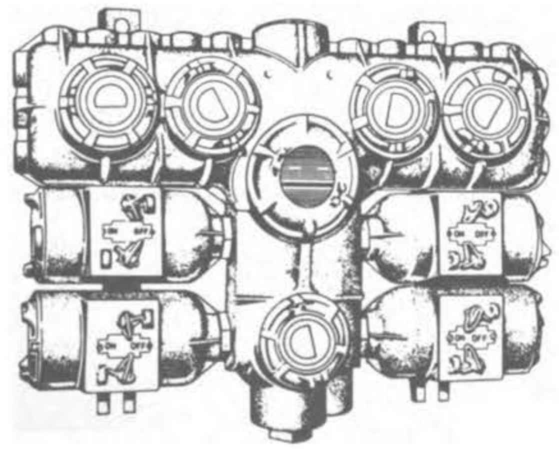


Fig. 3. Explosionproof panelboard enclosure (NEMA Type 7).

NEMA Classification for Enclosures for Industrial Control Apparatus

Following are the type numbers assigned by NEMA (National Electrical Manufacturers Association) to identify some of the various types of nonventilated enclosures. A list of types and the definition of each are given, including those not designed for hazardous locations. When ordering devices for hazardous locations, the applicable NEMA-type enclosure is often specified. The NEMA-type numbers usually are not marked on the enclosures but are included in the manufacturer's catalogues.

Type 1, General purpose—Indoor is an enclosure intended primarily to protect against accidental contact of personnel with the enclosed equipment.

Type 2, Dripproof—Indoor is an enclosure intended to protect the enclosed equipment against falling noncorrosive liquids and falling dirt.

Type 3, Dusttight, Raintight, and Sleet Resistant—Outdoor is an enclosure intended to protect the enclosed equipment against windblown dust and water.

Type 4, Watertight and Dusttight—Indoor and Outdoor is an enclosure intended to protect the enclosed equipment against splashing water, seepage of water, and falling or hose-directed water.

Type 6, Submersible, Watertight, Dusttight, and Sleet Resistant—Indoor and Outdoor is an enclosure intended for locations where occasional submersion is encountered.

Type 7, Class I, Group A, B, C, or D—Indoor Hazardous Locations is an enclosure for air-break devices intended for use in Class I, Groups A, B, C, or D hazardous locations.

Type 8, Class I, Group A, B, C, or D— Indoor Hazardous Locations is an enclosure for oil-immersed devices intended for use in Class I, Groups A, B, C, or D hazardous locations.

Type 9, Class II, Group E, F, or G—Indoor Hazardous Locations is an enclosure for air-break devices intended for use in Class II, Groups E, F, or G hazardous locations.

Type 10, Bureau of Mines is an enclosure designed to meet the requirements of the U.S. Bureau of Mines which relate to atmospheres containing mixtures of methane and air, with or without coal dust present.

Type 11, Corrosion Resistant and Dripproof—Indoor is an enclosure for oil-immersed equipment intended to protect the enclosed equipment against dripping, seepage, and

*Table 1. Equipment Recommended For Locations Containing Flammable Vapors Or Gases (Class I).**

	Division 1	Division 2
Wiring	Threaded rigid metal conduit or Type MI cable. Explosionproof boxes and fittings. Use seals to prevent passage of gases, vapors, or flames through conduit from one portion of electrical installation to another.	Threaded rigid metal conduit, enclosed gasketed busways, or Type MI, MC, ALS, CS, TC, or SNM cable. No seals required except where explosionproof equipment is necessary and conduit leaves hazardous area. Wiring, which under normal conditions cannot release sufficient energy to ignite a specific hazardous atmospheric mixture, can be accepted using any of the methods suitable for wiring in ordinary locations.
Switches, circuit breakers, and motor controllers	Install in an enclosure approved as a complete assembly for Class I, Division 1 locations. (Enclosures approved for Class I, Division 1 locations include explosionproof and purged and pressurized enclosures.)	Same as Division 1, unless general purpose enclosures are provided and the interruption of current occurs in hermetically sealed chambers or the contacts are oil-immersed. (General-purpose enclosures are acceptable for isolating or disconnecting switches without fuses and not intended to interrupt current.)
Fuses	Install in an enclosure approved as a complete assembly for Class I, Division 1 locations. (Enclosures approved for Class I, Division 1 locations include explosionproof and purged and pressurized enclosures.)	Install in an enclosure approved for Class I, Division 1 locations, for fuses protecting motors, appliances, and portable lamps. General purpose enclosures are acceptable for these fuses if the operating element of the fuse is oil-immersed or in hermetically sealed chamber. (General-purpose enclosures are acceptable for fuses on circuits to fixed lamps.)
Receptacles and attachment plugs	Polarized type approved for Class I locations, having provision for connection to grounding conductor of flexible cord.	Same as Division 1.
Motors and generators	Approved for Class I locations, or totally enclosed type supplied with positive pressure ventilation from a source of clean air , or totally enclosed inert gas filled type supplied with a source of inert gas to pressurize the enclosure.	Enclosure approved for Class I locations for rotating electrical machines employing sliding contacts, centrifugal or other switches or integral resistors, unless such contacts, switches, and resistors have enclosures approved for Class I, Division 1 locations. Open polyphase squirrel-cage induction motors without brushes or switches are acceptable. (Total enclosed polyphase squirrel-cage induction motors are preferable for new installations.)
Lighting Fixtures	Fixed and portable units approved as complete assembly for Class I, Division 1 locations. Fixtures should have guards surrounding the globes or be located so as not to be subject to physical damage.	Fixed enclosed gasketed globes or other effective protective means where (a) flammable liquids are in the open, or (b) sparks or hot metal from lamps or fixtures might ignite local concentrations of flammable vapors or gases. Use lamps of a size or type that do not reach surface temperatures in excess of 80% of the ignition temperature (°C) of the gas or vapor involved; or use fixed fixtures approved as complete assembly for Class I, Division 1 locations. Other fixed lighting units may be ordinary open type without switches, starters, or control equipment. Fixtures for fixed lighting should have guards or be located so as not to be subject to physical damage. Portable lamps to be approved as complete assembly for Class I, Division 1 locations.
Transformers and Capacitors	Install units containing either flammable or nonflammable liquid in approved vaults having no openings to hazardous areas, or use units approved for Class I locations for those that do not contain a liquid that will burn.	Install according to rules for nonhazardous locations.
Meters, relays, and instruments	Enclosure approved for Class I, Division 1 locations, or intrinsically safe equipment. (Enclosures approved for Class I, Division 1 locations include explosionproof and purged and pressurized enclosures.)	Equipment containing make-and-break contacts in enclosures approved for Class I, Division 1 locations. General purpose enclosures are acceptable if current-interrupting contacts are (a) oil-immersed, or (b) hermetically sealed, or (c) in circuits that under normal conditions do not release sufficient energy to ignite a specific hazardous atmospheric mixture, i.e., are non-incendive. Equipment, such as transformer windings, solenoids, and other windings that do not contain sliding or make-and-break contacts acceptable in general purpose enclosures.

*Wherever possible, locate electrical equipment outside of hazardous areas. More specific details are given in Article 501 of the National Electrical Code. See the National Electrical Code for details on equipment not covered in Table 1.

*Table 2. Equipment Recommended For Locations Containing Combustible Dusts (Class II).**

	Division 1	Division 2
Wiring	Threaded rigid metal conduit or Type MI cable. Use units approved for Class II locations for boxes or fittings containing taps, joints, or terminal connections or if dusts are combustible and electrically conducting. Seals needed in conduit connecting dust-ignitionproof and non-dust-ignitionproof enclosures.	Rigid metal conduit, electric metallic tubing, or Type MI, MC, ALS, CS, or SNM cable. Same as Division 1 for sealing.
Switches, circuit breakers, and motor controllers	Install in an enclosure approved as a complete assembly for Class II, Division 1 locations for devices that normally interrupt current or where dusts are combustible electrically conducting. (Enclosures approved for Class II, Division 1 locations include dust-ignitionproof and purged and pressurized enclosures.) Isolating or disconnecting switches without fuses and not subject to these conditions should have tight metal enclosures and covers to minimize entrance of dust and to prevent escape of sparks or burning material.	Install in a tight metal enclosure with close fitting cover to minimize entrance of dust and to prevent escape of sparks or burning material.
Fuses	Same as for other spark-producing devices above.	Same as for other spark-producing devices above.
Receptacles and attachment plugs	Polarized type approved for Class II locations, having provision for connection to grounding conductor of flexible cord.	Polarized type with grounding connection and so designed that connection to the supply circuit cannot be made or broken while live parts are exposed.
Motors and generators	Dust-ignitionproof or totally enclosed pipe ventilated and approved for Class II locations.	Dust-ignitionproof or totally enclosed pipe ventilated, for which maximum surface temperature does not exceed 120°C (248°F). Where moderate accumulations of nonconducting nonabrasive dust occur and equipment is accessible for cleaning, it is acceptable to use (a) self-cleaning textile-type squirrel-cage motors, or (b) standard open motors without sliding contacts, switches, or resistance devices.
Lighting fixtures	Fixed and portable units approved for Class II, Division 1 locations. Provide guards or locate to prevent physical damage.	For fixed lights, provide enclosures to minimize dust deposits, prevent escape of sparks or burning material, and maintain exposed surface temperature less than 165°C (329°F). Provide guards or locate to prevent physical damage. Portable units approved for Class II, Division 1 locations.
Transformers and capacitors	Install units containing flammable liquid in approved vaults. Any openings to hazardous areas should be protected by double, tight-fitting, self-closing fire doors. Ventilating and pressure-relief openings should communicate only to outside air. Install units that do not contain a liquid that will burn in approved vaults, or use those approved as a complete assembly for Class II locations.	Install units containing flammable liquid in approved vaults. Install dry-type transformers in vaults or tight metal housings without openings, and do not operate at voltages above 600 volts. Install askarel transformers in accordance with rules for nonhazardous locations. Locate these transformers so that there is an air space of not less than 6 in. (15.2 cm) between the transformer cases and any adjacent combustible material.
Meters, relays, and instruments	Enclosure approved for Class II, Division 1 locations or intrinsically safe equipment. (Enclosures approved for Class II, Division 1 locations include dust-ignitionproof and purged and pressurized enclosures.)	Tight metal enclosures and covers to minimize entrance of dust and prevent escape of sparks and burning material.

*Wherever possible, locate electrical equipment outside of hazardous areas. More specific details are given in Article 502 of the National Electrical Code. See the National Electrical Code for details on equipment not covered in Table 2.

external condensation of corrosive liquids and the corrosive effects of fumes and gases.

Type 12, Industrial Use—Dusttight and Driptight—Indoor is an enclosure intended to protect the enclosed equipment against lint, fibers, flyings, dust and dirt, and light splashing, seepage, dripping and external condensation of noncorrosive liquids. It has an oil-resistant gasket between the case and cover. There are no unused holes through the enclosure for mounting controls within the enclosure and no conduit knockouts or conduit openings.

Type 13, Oiltight and Dusttight—Indoor is an enclosure intended to protect the enclosed equipment aginst lint and dust, seepage, external condensation, and spraying of water, oil, or coolant.

NOTE: The material herein generally conforms with NFPA No. 70, *National Electrical Code,* NFPA No. 493, *Intrinsically Safe Apparatus for Use in Class I Hazardous Locations and Its Associated Apparatus,* and NFPA No. 496, *Purged and Pressurized Enclosures for Electrical Equipment.*

FMELPC July 1976

August 1976

COMBUSTIBLE DUSTS

SUPERSEDES HANDBOOK PAGES 40-29, 40-32, 66-1 TO 66-9, 66-14 TO 66-16

SCOPE

This data sheet discusses the fire and explosion hazards inherent in the processing, storage, and handling of combustible dusts and materials which produce combustible dusts. Recommendations presented are applicable to a wide variety of industrial occupancies such as candy manufacturing, metal powder production, and sugar refineries.

Specific recommendations for the protection of dust collection equipment are presented in another data sheet. Specific recommendations for flour, feed and grain storage and processing are also presented in another data sheet. These two exceptions are made to give these items the necessary attention which loss experience and number of installations dictate.

GENERAL INFORMATION

Combustible dusts present both fire and explosion hazards.

The principle fire hazards are (1) the ease of ignition of finely divided combustible material with consequent ignition of other less easily ignited materials, and (2) the possibility of deep-seated difficult-to-extinguish fires developing in dusts.

The principle explosion hazard is the pressure produced by rapid combustion causing rupture of equipment and collapse of structures. An important additional consideration in the event of explosion is the disruption of fire protection equipment and consequent large fire loss.

Recommendations presented in this data sheet are divided into two categories: prevention and protection.

The same basic *prevention measures* apply for both fire and explosion. They are: (1) good housekeeping, (2) elimination of ignition sources, (3) isolation of dust producing operations from nondusty operations and subdivision of large operations into smaller ones where practical, and (4) education of employees as to the hazards presented.

The basic *protection measure* against *fire hazard* is the installation of fixed automatic protection equipment and the use of noncombustible material. An important consideration is the ability of the fire protection system to function following an explosion.

The basic *protection measure* for the *explosion hazard* is the use of damage-limiting construction. Damage-limiting construction for both buildings and equipment consists of construction strong enough to withstand the effects of an initial internal explosion or weak enough to fail without appreciable structural damage. Vents are an important part of the damage-limiting concept.

An additional protection measure for the explosion hazard is the use of a Factory Mutual approved explosion suppression system.

LOSS EXPERIENCE

Fire and explosion loss experience for the 10-year period ending in 1973 shows that although dusts were not always heavily involved, they were a contributing factor in almost 10% of the total dollar loss.

More than half of the fires and explosions occurred from sparks due to friction and tramp metal. Local overheating caused about 15%. Static sparks, electrical faults, or improperly safeguarded cutting or welding were responsible for most of the remainder.

Fire loss experience shows three classes of losses: (1) Repetitive losses of less than $50,000 in dust collection equipment; (2) losses up to and over $250,000 involving deep-seated burning in large piles of agricultural and mineral products; and (3) losses ranging up to many millions of dollars involving both fire and explosions where fire protection has been made ineffective or inoperative by the initial and subsequent explosions.

Examples of these types of losses follow:

Repetitive Fires. Cloth bag dust collectors were installed for zinc volatiles according to Environmental Protection Agency requirements at a brass foundry. Spontaneous heating of the zinc caused ignition of collected zinc dust and the cloth bags. Sprinklers extinguished the fires and preserved the frame of the housing, but in each case equipment and production were lost. There were multiple losses each totalling $10,000 to $30,000. (1972, 1973)

Deep Seated Burning Fire. One section of a typical large modern concrete grain elevator was being loaded with soy beans, when apparently a static spark ignited a small dust cloud which in turn ignited the soy beans. An opening to a second silo resulted in fire loss to the contents of that silo also. Damage to soy beans and the structure from the fire resulted in a fire loss of $250,000 (Note there was no explosion damage.) (F-2681, 1969)

Fire and Explosion. With noncombustible construction, the predominant loss cause is explosion. The typical loss is similar to that which occurred at the flour mill discussed below. Combustible construction could result in a total burnout. See X-41, 1972

Although all explosion losses are serious, the greatest amount of property damage and business interruption would be as a result of: (1) repetitive small losses, and (2) initially small losses which result in chain reaction explosions. Examples follow:

Repetitive Loss. Fire and Explosion. A series of fires and explosions occurred in a dryer at a hardboard manufacturing plant. These fires were inherent to the process and each resulted in losses of over $10,000 combined property damage, and business interruption. As a result of these losses, a Factory Mutual approved explosion suppression system was installed, which has reduced the amount of damage in subsequent losses. (X-47, X-139, X-143, X-199, 1966)

Large Loss. Fire and Explosion. Railroad cars were being bulkloaded from storage bins in a major flour mill. A spark from tramp metal ignited flour which spread flames and produced pressures throughout ductwork. Chain reaction explosions occurred throughout the building. The outer wall of a nine-story masonry section collapsed onto an adjacent four-story section, a utility building, and a train shed causing severe damage to these structures. Fires ignited in several adjoining buildings, and a warehouse suffered severe damage from this fire. Sprinkler piping in the warehouse was broken in the explosion and collapse. Basement areas were flooded. Loss was over $6,000,000 PD and $8,000,000 BI. (X-41, 1972)

FIRE AND EXPLOSION HAZARDS OF COMBUSTIBLE DUSTS

Fire Hazard

Noncombustible or fully oxidized material will never burn no matter how finely divided, but combustible materials when finely divided are easy to ignite. Combustible dusts include finely divided iron, normally considered to be noncombustible material, and finely-divided wood, normally considered to be combustible but not an explosion hazard. If the dusts are not suspended in air but are provided with sufficient oxygen or other oxidizing material, they burn or smolder when an ignition source is provided. The fact that they are easily ignited makes them an excellent tinder to start larger fires involving less easily ignited material. An example is wood dust igniting the nylon fabric in a dust collection system. A spark which normally could not ignite a nylon fabric could ignite a layer of wood dust which in turn would cause ignition of the fabric.

Quiescent combustible dusts are normally closed packed with little air space between particles. They are often subject to slow burning burrowing fires which ultimately consume large quantities of material, but produce heat at a low rate. An example of this type of fire is grain mixed with its own dusts. Fires of this type smolder for days or weeks before final extinguishment can be accomplished. Smoldering combustion not only destroys the value of the materials being consumed, but damages adjacent material, often making it unfit for further use.

Explosion Hazard

The explosion hazard of a combustible dust is an extension of the fire hazard. Whereas a quiescent combustible dust most often burns slowly, the same combustible dust when suspended in air in a concentration above its lower explosive limit undergoes rapid combustion. The heat of combustion expands the unburned gases and products of combustion, resulting in pressure which must be either relieved or withstood.

Analogy to Flammable Vapor

The explosion hazard of a combustible dust is similar to the explosion hazard of a flammable liquid vapor or a combustible gas. The major difference is that a dust must be put into suspension by some outside mechanism before an explosion can occur, whereas the flammable liquid vapors and combustible gases have their own capability of diffusing with air to provide possible explosive mixtures.

Upper and Lower Explosive Limits

The Lower Explosive Limit (LEL) is the minimum concentration of combustible dust in the suspending medium (usually air) which will propagate a flame. The average LEL is about 0.065 ounces per ft^3(65 grams per cubic

GRAIN DUST EXPLOSIONS - THE TIME HAS COME TO BITE THE BULLET

A. S. Townsend, C. P. C. U.
May 26, 1978

Preface

This paper distills the observations, conclusions and recommendations of three individuals who have been engaged for the past thirty years in underwriting and fire prevention for grain elevators, feed mills and other grain-related risks. It does not purport to represent a consensus of the insurance industry because, regrettably, no such consensus exists. Neither can it be considered a scientific presentation in the strict academic sense; the physical elements are too diverse, and the imprecisions of economics and statistics are unavoidable.

It is the firm opinion of the author and his associates that (a) the causes of grain dust explosions are readily identifiable through scientific data long at hand (b) the escalation of explosion frequency beginning in January of 1976 is explainable--indeed was even predictable (c) the technology for eliminating major disasters already exists, and (d) failure to promptly confront the problem will inevitably bring further loss of life, and chaos in international trade.

Let it be stressed that the purpose here is not to dramatize disasters or second-guess those who have been victims of them; it is rather to synthesize the varied bits of knowledge which are essential to a solution, but which heretofore have reposed in scattered archives or lived within the experiences of a small group of persons whose vocation let them learn but did not induce them to teach.

The grain dust explosion problem is almost two hundred years old, the first recognized incident allegedly being a flour mill explosion in Turin, Italy, in 1785. United States statistics, although they are extremely inaccurate because of no valid reporting system, have been partially recorded for 100 years, the first spectacular blast occurring in Buffalo in 1913 when 33 people were killed in a feed mill. From then until 1976, the annual average of major grain dust explosions was something like 5. Then, in January of 1976, two disasters killed 14, injured 20, and initiated a catastrophic sequence of 26 tragedies which peaked during the 6 days between December 14 and 19, 1977, when 4 explosions killed 52 and injured many more. At least 2 fatal explosions have followed.

The December debacle triggered demands for action. The series of 26 explosions between January, 1976 and December, 1977 gave rise to the illusions that grain elevator explosions were either a totally new and mysterious phenomenon, or that there had been a proliferation of them far in excess of the actual fact. By best available figures, the average annual incidence of major dust explosions during the period 1958-1975 is 8. The annual average for 1976-1977 is 13, an increase of 63%. Can the causes for the new frequency be explained?

It can easily be demonstrated that three components must exist simultaneously to produce a dust explosion: oxygen, an ignition source and, air-suspended dust. Oxygen, as a practical matter, is not controllable in the total volume of a grain elevator; so two variable components remain--ignition sources and dust. The mathematical probability of air-suspended dust and an ignition source existing simultaneously is the product of their respective probabilities of existing independently. Thus, if the time of dust suspension is doubled, and the ignition sources are doubled, the probability of simultaneous occurrence is quadrupled. Therefore, to produce an increase of 63% in simultaneous occurrence, the time of dust suspension and the ignition sources need be increased by only 27% each, and a most casual appraisal will certainly confirm that they have been. When such current realities as (1) lighter, finer, drier dust from filtration and recirculation (2) poorly designed, improperly installed, faultily maintained and inadequately understood filter-type dust-control equipment (3) inability to control in-house dust because of conflicting EPA, OSHA and USDA requirements (4) economic and regulatory mandates to recirculate captured dust (5) increased volumes and accelerated handling speeds at harvesting combines, on-farm drying and additional handling from farm to terminal elevator (8) proliferation of ignition sources, and (9) the synergistic effect of increased incidence of both variable explosion factors-- when all are considered *en masse*, as they must be, a new paradox arises: why have there not been even more dust explosions?

If, in the light of what has just been suggested, it can be demonstrated that typical filtered grain dust at less than 14% moisture content can be exploded consistently by either heat or spark, and that at moisture contents significantly above 14% the explosibility is only reduced, but not eliminated, then there is prima facie evidence that dust is the explosion fuel, and the futile, time-wasting search for exotic agents can be abandoned in favor of a real solution. Fortunately, such is the case, and we can set about the business of dust control without pretext or procrastination.

The question is sometimes asked "what causes clean elevators to explode?", and the implication has undoubtedly lent credence to the "something-other-than dust" theory. But do clean elevators explode? What is a clean elevator? Never have definitive standards been published for either hazardous dust suspensions or static dust accumulations. "Clean" has generally been a comparative term, meaning "cleaner than the elevator across the bay"; "Good housekeeping" all too often means shoveling truck-loads of settled dust between runs.

For many years laboratory experimentation has placed the lower explosive limit of mixed grain dust at about .04 oz./ft.^{3}, or 40 gms./mtr.^{3}. On that basis, assuming an approximate dust weight of 18.5 lbs./ft.^{3}, a tunnel 400' x 10' x 8' could be theoretically explosified by a floor accumulation .013" deep. Even allowing for substantial flexibility in these figures, it becomes apparent that dust need not be shoe-sole high to create an explosive potential.

A successful attack entails the removal of at least one of the three combustion factors--the oxygen, the ignition source, or the fuel. Conceding the oxygen to be uncontrollable, efforts must be directed toward ignition sources, or dust, or both. But can either one be so minimized as to guarantee against a major explosion? It is obviously prudent to reduce the likelihood of spark or flame to the lowest feasible level, but experience has shown that even then an unacceptable plethora remains (lightning, friction fires, static sparks, electrical malfunction, human error, etc.). Here, then, the issue of workable dust-control is framed.

Indeed a preponderance of elevator operators, as a consequence of disappointing results with filter dust-control systems, will aver in good faith that dust cannot be reduced to the minimal quantities necessary for explosion safety. Their cynicism is justified, and the reasons for it will be hereinafter implied. But there are clean elevators--dust is being controlled, even to the exacting breathability standards of OSHA, which, at 15 mg./mtr.^{3}, is approximately 1/2,600 of the lower explosive limit.

The escalation of explosion frequency beginning in January of 1976 is attributable to several causes, principal among which, in the author's view, are the regulatory requirements that dust not be emitted to the atmosphere (EPA), and the de facto or imaginary rule that it be recirculated in the stock-stream (FGIS). There is also an economic compulsion to retain grain dust under present weighing and grading rules, because he who buys dust must either sell that dust or bear the loss.

The result is retention of captured dust which has been finely particleized and super-dried by a succession of filtrations and thereby refined into its most explosive state. And the danger is compounded by the fact that even adequately designed filter-collectors are overwhelmed by the introduction of dust from many preceding filters, both at the terminal elevator and at those inland. The manometers and magnehelic gages which indicate the degree of blockage in filter-collectors give mute, unheeded warning that the dust control systems in many elevators are partially or totally disabled, and under these conditions the collector literally becomes the "cork" which bottles explosion fuel within the house.

It is ironic that the explosive dust averages something less than 0.10% of the total grain weight, and that it can be mechanically separated from the harmless heavy particles with relative ease; yet we tenaciously persist in the custom of keeping it with the grain from whence it came rather than removing it as it is generated. The minuscule unit monetary loss occasioned by removal, perhaps three-tenths of a cent per bushel, could ultimately be passed forward to the consumer by a realistic weighing and grading system; the nutritional content of the separated dust could be salvaged as a pelletized animal feed ingredient; and filter dust-control systems could function as intended from country elevator to export terminal.

In support of the assertion that dust-control is sine qua non of explosion prevention, it is noted that eyewitness accounts of disasters uniformly describe a rapid series of detonations rather than a single blast. The series usually begins with a minor, localized flash which, of itself, is inconsequential. But the air movement caused by pressure of the first ignition is more than sufficient to put static accumulations into suspension. Indeed, the air velocity created by the stream from a hand fire extinguisher has been known to raise volatile clouds. Clearly, it is the secondary and successive explosions which are cataclysmic. Concrete elevators, with very little pressure-venting area, confine the rapidly expanding air and direct it vertically through the head-house and laterally through the tunnels under the silos and the galleries above them. Static dust in all parts of the house is thrown into suspension, and wherever the lower explosive limit is attainable, a further explosion is fired by the ignition already in progress from the preceding one. This deadly progression cannot occur where there is insufficient static dust--safe housekeeping is absolutely essential to the elimination of destructive explosions.

Long recollections indicate an unmistakable relationship between cold weather and dust explosions. Nebulous associations have prompted speculation that (a) dust is dried by cold, low-moisture air, and (b) the low relative humidities of winter foster conditions under which static electricity accumulates. There is, of course, substantial foundation for both theories, but an illusory panacea has evolved from their misapplication. It is imagined by many that explosion danger subsides when the outdoor relative humidity climbs above a certain value, usually thought to be about 45%. The rationale holds that either the dust becomes too moist to explode or that static electricity is eliminated as an ignition source by "drainage" through moisture film deposited on non-conductive bodies.

So many explosions have occurred during very high outdoor humidity that the "damp dust" notion can be discarded; and static charges to 300,000 volts can readily be measured on ungrounded conveyor frames, one example of which an associated detected during a snow storm last January.

A large firm which specializes in de-statifying industrial properties will not tackle grain elevators, because several fruitless attempts have brought them to the conclusion that "a grain elevator is one huge capacitor".

A good explanation of the static electricity--relative humidity interaction is found in NFPA 77, wherein it is stated that certain non-conductive surfaces absorb water vapor from the atmosphere to the point where an equilibrium is reached, that equilibrium point being dependent upon the actual amount of moisture in the air as compared to the total moisture which the air is capable of holding at a given temperature (relative humidity). The theory, however, assumes normal pressure and undisturbed air; and it specifically excepts certain surfaces which do not absorb or retain sufficient moisture to dissipate static voltage. Plastics are cited as an example of such surfaces, and PVC (plastic) belting is to be found in almost all U. S. grain elevators. Neither is the pressure normal nor the air calm inside of the stock-handling system of an elevator. Strong negative pressures (upwards of 20" of water) are necessary in the dust-control duct-work, and these develop air velocities in excess of 4,000 f.p.m. The evaporative effects of reduced pressure and rapid air movement, and the inherent moisture-rejection of plastic belting explain the common paradox of high relative humidity and low temperature at the local airport while the cup-bolts in a bucket elevator belt spark like an ignition system as they approach the grounded head pulley.

Although dust control must be the prime objective in prevention, static electricity is highly suspect as the ignition source in a long record of cold-weather, "source-unknown" dust explosions. The metallic components of a grain elevator can be easily and effectively bonded and grounded; it is the non-conductive conveyor belting and bucket-elevator belting which is impossible to de-statify. Conductive belting and pulley lagging show good promise and have solved the static problem in those few experimental situations where it has been used.

Toward a universal comprehension of the cold weather--dust explosion relationship, it is here urged that temperature, static voltage and specific humidity as well as relative humidity be continuously monitored and recorded, with and without conductive belting and lagging in identical environments. The drying effect of low specific humidity upon fine dust should also be studied, so that the truths can be accepted and the myths dispelled.

Those close to the dust explosion problem know that its resolution will be expensive, and disruptive to conventional routines. Management priorities have traditionally been production first, and housekeeping as time permits. This is completely understandable in view of the seasonal nature of the crops handled, delivery schedules, demmurage charges and a host of other compulsions to keep the elevator running. But this order is not compatible with the stringent regulatory requirements of no dust emission to the atmosphere and no accumulations within the house. A few large grain handlers have already issued firm orders to all plant managers that malfunction of a dust control system will immediately cause the plant to be shut down. Responsibility for the interruption is assumed by a staff executive.

Several recommendations are propounded in an addendum for both the immediate and long-term abatement of the explosion crisis. Some of them will be critized as unduly onerous or unworkable. But they have not been hastily assembled under duress of the current dilemma; they evolved slowly from literally thousands of inspections, discussions with many grain people from sweeper to top executive, and constant dialogue with others in the business of loss prevention.

The choice now seems to be whether the grain industry will embark voluntarily and promptly upon a course which will take it to the objective, or whether more tragedies will force irrelevant panic regulation upon it by those less qualified to lead the way.

It is perhaps atypical that a spokesman for one segment of the grain property insurance industry should hold forth at length upon the physical aspects of the explosion situation, to the total exclusion of the underwriting repercussions which it has created. But because the problem is purely a physical one, suffice it here to say that the world reinsurance markets are on the brink of abandoning large elevator risks. They have been, for the most part, admirably patient, but there is a limit of losses beyond which even dependable Lloyds of London cannot go. Increased rates can recoup past losses in due time, but no affordable rate level will sustain the frequency and severity of losses of the past two and one-half years. Underwriting gimmickry such as large deductibles, industry pools, captive insurance companies, and stacks of excess coverage layers merely deny the difficulty and so prolong its duration.

That the potential for major destruction exists in as many as 70% of U.S. elevators is probably a reasonable and supportable statement. The time has come to bite the bullet.

GENERAL RECOMMENDATIONS FOR CONTROL OF DUST EXPLOSION FREQUENCY AND SEVERITY

1. Weighing and grading standards which require complete and continuous removal of fine dust of less than 40 microns particle size.

2. Complete mechanical dust-control systems capable of maintaining adequate negative pressures in all enclosed components of stock-handling systems (elevator legs, distributor bins, etc.); and capable of capturing all dust at other emission points (loaders, spouts, etc.) so that explosive suspensions cannot exist in any part of the plant during normal operations.

3. Prior approval of dust-control system plans by an engineer <u>certified</u> in dust control design; <u>licensing</u> of installers.

4. Mandatory regular inspections of dust-control systems and their performance.

5. Mandatory written and verbal instruction of operating personnel by designer or installer.

6. Adoption of "automatic" features into dust-control system design to minimize human error (continuous tunnel conveyor hoods to eliminate need for manual operation of blast-gates, etc.)

7. Pressure differential gages on filter collectors to be accessible for mandatory daily reading and recording. All manometers to be clearly and permanently labelled with reading instructions.

8. Prohibition of dust recirculation.

9. Mandatory shut-down when any dust-control system becomes dysfunctional.

10. Captured dust less than 40 microns to be stored outside of elevator building.

11. All Belting and pulley lagging to be conductive with complete bonding and grounding of all major metallic bodies within the elevator building.

12. In all new elevator designs, elimination of tunnels, galleries, head-houses and large interior elevator legs.

13. General minimization of ignition sources to be continued according to established standards (National Electric Code, NFPA, etc.), but the relationships among static electricity, temperature, relative humidity and <u>specific humidity</u> to be researched further with results of that study to be published throughout the industry and its regulatory bodies.

14. Meaningful, quantitative, standards to be established for "housekeeping", so that hazardous dust suspensions and static accumulations might be measured by everyone with the same yardstick.

DUST CONTROL IN GRAIN ELEVATORS

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June 1, 1978

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DUST CONTROL IN GRAIN ELEVATORS

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June 1, 1978

INTRODUCTION

Background

The unusual occurrence of several elevator explosions last winter has received dramatic attention from the public and government regulatory agencies. Elevator explosions were nothing new and had been occurring for many years. However, the relatively large number in a short period of time with a heavy toll of over 50 lives has focused attention on this hazard of the grain industry. With such attention, it appears grain elevator explosions are not a short term problem, but instead a long term problem for which the grain industry needs to find workable solutions.

The four basic elements for a grain explosion are: 1) an oxygen source, 2) a fuel source, 3) an ignition source, and 4) a confined space.

This paper will discuss the fuel source, which in the case of grain explosions is grain dust, and control of this dust. Dust control itself is a relatively broad topic. This paper dwells mainly on dust control as it relates to dust explosions. It is a practical approach to the problem. The methods discussed are known, state of the art methods that can be practically applied in most of today's grain elevators.

These discussions refer to a quasi-coverage of all grain elevators ranging from the small, country elevators to terminal facilities. In addition to such elevators not related to processing, there are grain elevators which are a part of a grain processing facility. These include elevators at feed mills, soybean processing plants, and at flour and other cereal milling plants.

Reasons for Dust Control

Following the rash of explosions last winter dust control has been widely discussed by elevator operators, industry leaders, and government authorities, mainly as it relates to grain dust explosions. Other reasons for dust control should be considered. Usually there are

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other reasons besides eliminating explosion hazards that require an elevator owner to provide dust control, or in some cases even offer economic incentives for dust control. Therefore, explosion control by elimination of dust should not be the sole consideration for providing dust control.

It should also be noted that during 1977 the U. S. EPA proposed new air pollution standards for grain elevators. These proposed standards were initially released in January of 1977, received for public comment, and a proposed final draft standard released in August. These standards, which have been revised from the initial draft and the August draft, are scheduled to be promulgated into law in July, 1978. While their impact on all elevators has been substantially reduced, it still places dust control requirements on grain elevators.

In addition to the explosion hazard and air pollution requirements, the following "positive" reasons for dust control are listed:

- Change in electrical code classification such that less expensive electrical equipment can be used. In many elevators dust control can mean the difference of an elevator being classified Division 2 instead of the more stringent Division 1. In some cases savings on electrical equipment and motors has substantially paid the cost of dust control.
- Less shrink and loss of product.
- Improved overall operating efficiency.
- Lower overall maintenance costs. While there is the additional maintenance cost of dust control equipment, in most cases the net overall result of properly applied dust control is reduced maintenance costs.
- Better employee incentives by offering a cleaner place to work.
- Better public relations with industry neighbors and the public.

THE "OPEN-UP" THEORY

In recent months there has been speculation by some people stating EPA air pollution requirements and dust control as a cause for the rash of dust explosions. In the opinion of the author this is simply backward thinking that only serves to hinder solutions to the problem.

For an explosion to occur the fuel and oxygen must be in a confined space. Therefore if an elevator facility was fully "open" there may be some justification for the above claim. If there were no tops on bins, the elevators had no enclosed legging, the conveyors had no covers, and the workhouse had a series of decks setting on columns without walls; then there would certainly be less potential for dust explosions. However such an approach is completely out of the question. In most parts of the country, and particularly where most elevators are located, grain must be protected from the weather. Further, such an "open design" approach would also mean tremendous dust emissions to the atmosphere, which appears entirely unacceptable to the United States public.

Once a building or equipment is "enclosed" then it might as well be closed completely. Unless openings are provided at the known effective ratios of 1 square foot of open (or relievable) area to 30 to 80 cubic feet of enclosed volume, then it would actually be better to completely close or seal the bin or equipment. In other words there is no practical in-between. Either open it up completely or close it up completely.

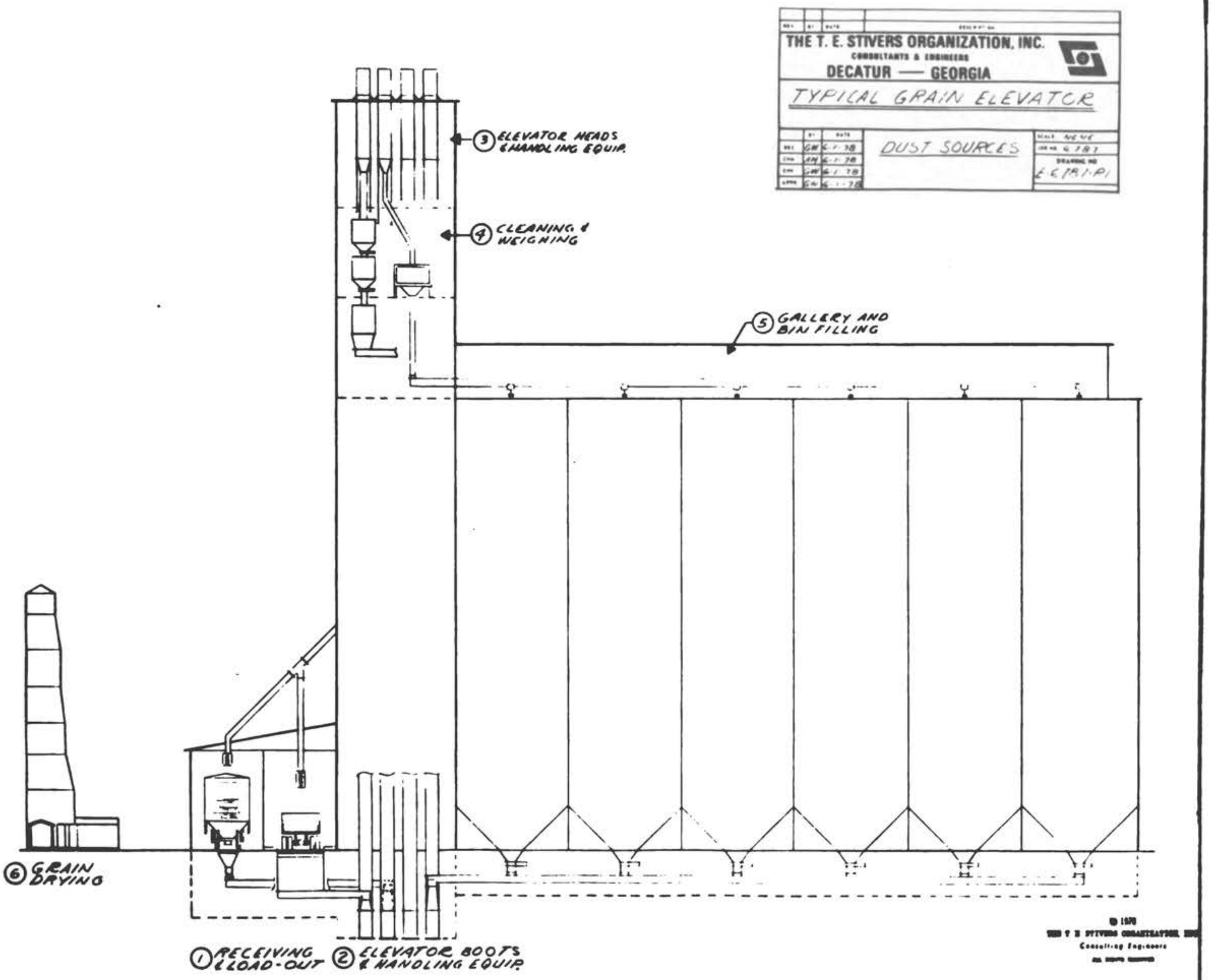
DUST SOURCES AND CAUSES OF DUST

The illustration, "Dust Sources", on the following page shows a "typical" grain elevator. It should be noted that this is not used to illustrate an "optimum design", but merely to show something representative of the 5,000 to 10,000 grain elevators in this country, to form a basis for our discussion. The following grain elevator dust sources are noted:

1) Receiving and Load-out

Truck and rail are the means of receiving in most elevators. Trucks are usually lifted with a truck dumper to empty the grain into a receiving hopper. As the truck is lifted and grain starts moving and falling into the receiving hopper a tremendous amount of dust is generated. Some hopper bottom trucks are used. When the hopper bottom opens and grain begins to discharge dust is generated. Also if grain is metered out of the hopper bottom, instead of full flow, or metered from any other truck for that matter, dust is generated. The same thing occurs if the tailgate of a truck is opened part way.

Most rail receiving is from railroad hopper cars, although a few boxcars are still used. The rail hopper car is unloaded in the same manner as the hopper bottomed truck by opening the discharge slide gates. Again, dust is emitted at this point and particularly if the slide gates are used to meter the grain.



REV	BY	DATE	DESCRIPTION

THE T. E. STIVERS ORGANIZATION, INC.
CONSULTANTS & ENGINEERS
DECATUR — GEORGIA

TYPICAL GRAIN ELEVATOR

	BY	DATE
DES	GW	6-1-78
CHK	AM	6-1-78
DRN	GW	6-1-78
APPR	GW	6-1-78

DUST SOURCES

SCALE NONE
JOB NO 6787
DRAWING NO
E-6787-P1

DUST SOURCES

Load-out of grain to trucks and rail cars is also a source of grain dust. Most elevators use gravity flow spouts to load trucks and rail cars. The spouts usually originate in the upper headhouse at the elevator discharges and gravity flow to the load-out, or loading area. The grain usually reaches relatively high velocities, entraining large amounts of air. When the grain discharges from the spout a tremendous amount of dust is emitted. As the grain falls into the truck or rail car, large amounts of dust continue to emit.

It is also noted that the previously referenced EPA Proposed Standards for Grain Eelvators lists 10 emission, or dust, sources within a grain elevator. Eight of these sources are truck, rail, ship and barge loading, and unloading stations which are generally not as great of an explosion hazard as other areas, such as the workhouse basement and tunnels and gallerys. For this reason ship and barge loading and unloading are not discussed in this paper.

2) Elevator Boots and Handling Equipment in Basements and Lower Levels

Conveyors in this area can be a source of dust, particularly where a conveyor is being loaded or discharged. Open conveyors can obviously be dust emitters.

Any leaks around the elevator boot pulley shafts and pockets can be a source of dust. An elevator acts similar to a fan with a positive and negative pressures. It can be a source of dust where there are leaks and positive pressure.

Spouts, chutes, and hoppers where grain is being handled can emit dust from the turbulence as grain is handled. Generally anywhere grain is moved a dust source exists.

3) Elevator Heads and Headhouse Handling Equipment

Elevator heads like the boot sections are a source of dust as a result of moving grain and entraining air. Like the boot sections they have positive and negative pressure effects. Generally the dust emitted at an elevator head is downstream in the spout from the discharge.

Conveyors, turnheads and other handling equipment can be a source of dust. Spouts and chutes handling grain are sources if they have leaks or are open. Generally there are longer spouting runs in the upper floors of a typical workhouse as compared to the basement and tunnel areas. These longer runs, as a result of higher velocity and entrained air, are a greater potential source than shorter spouts and chutes.

4) Cleaning and Weighing

Grain cleaners are a potential dust source. The screener types without aspiration move the grain and the resulting turbulence is a source of dust emissions unless the cleaners are kept sealed. Cleaners using air, or aspiration, are another potential source.

Bulk weighing systems with the upper and lower garners and a weigh hopper can emit dust as the hoppers are alternately filled and emptied.

5) Bin Filling and Gallery Areas

Anytime a bin is being filled it is a potential source of dust as grain is moved and dropped into the bin. Bins are usually filled by one of two arrangements. Elevators with the bins arranged in straight rows use some kind of conveyor to carry the grain to the bins and discharge into the bins. Other elevators have the bins in a cluster type of arrangement and use gravity spouts to fill the bins. As previously discussed, conveyors are a potential source of dust, particularly if open, and at the filling and discharge points. Also, elevators using belt conveyors with trippers can be a tremendous dust source.

6) Grain Drying

For purposes of this paper discussions on grain dryers as a source of dust are not included.

BASIC METHODS OF DUST CONTROL

It seems that the first thing that comes to mind when "dust control" is mentioned is a group of dust filters, fans, cyclones, and tremendous duct systems. Quite the contrary is true. In fact there are many methods of "dust control" that do not involve filters, fans and ducts. These are fundamental, basic dust control methods that are more economically feasible and should be carried out before spending money on dust suction systems with fans, filters and ducts. (It is assumed that with these "basic" methods, other appropriate measures of dust control and explosion relief venting are provided.)

Tight Spouting and Chutes

Spouting, chutes, hoppers, and other components handling grain should be maintained dust tight. A leak in a spout or chute can be a source of dust. Spouting should be of sufficient thickness for reasonable life. Heavy and/or abrasion-resistant materials should be used at major wear points. Flanges should be sealed. All welded connections should be continuously welded.

"Choke-Feed" Equipment

All equipment such as bin discharge conveyors and hopper feeder conveyors, should be choke fed. This eliminates grain falling and the resulting turbulence and dust emission such as from a cracked slide gate.

Tight Bin Tops

Bin tops should have all cracks and openings sealed. Manholes should be gasketed and dust tight. Filling spouts and any other openings in to the bins should be sealed.

As previously stated unless a bin top is going to have an open area sufficient to relieve an explosion, it should be closed and sealed. The cracks and crevices will not relieve an explosion and only serve as a source of dust for possible explosions elsewhere.

Closed and Sealed Equipment

Equipment such as conveyors and elevators should be completely enclosed and dust tight. Covers should be kept on conveyors and boot pockets. However, covers should have some quick opening inspection doors and clamps for cover removal. Otherwise, typically what happens is a maintenance worker has to remove a cover for a choke or repair. Then, rather than replace several bolts, the cover is left off or not sealed up. Provision must be made for convenient maintenance and operation of equipment.

Equipment should be specified to have gaskets and be dust tight.

Intervents

Intervents should be used at bulk weighing hoppers and similar equipment where grain is discharged in surges.

Intervents of elevator discharge spouts to the elevator down leg can also be effective in reducing dust emissions.

Short Spouting Runs

Spouting run lengths should be minimized. Equipment should be close coupled. This minimizes turbulence and entrained air and the resulting dust emission potential. Dead boxes can also be effectively used to decrease dust emissions on unavoidable long runs.

Eliminate Ledges

This is generally associated with dust control. However horizontal ledges in workhouses, galleries, and sheds accumulate dust. If an explosion occurs this dust can be jarred loose and become airborne, resulting in suspended dust sufficient for a secondary explosion.

In fact it is believed that such secondary explosions usually cause more damage than the initial explosion.

Elimination of ledges should be part of a dust control program. It can be accomplished cheaper and more conveniently in new construction. However flashing of existing ledges can probably be justified in some facilities.

Housekeeping

Another basic requirement for dust control is to encourage good housekeeping. This may require adding some concrete floor slabs in some areas and access stairs and platforms. Providing a convenient means for cleaning and housekeeping can help eliminate dust accumulations which can become airborne again and present an explosion hazard. Providing means for conveniently cleaning an area offers employee incentives.

Another means of good housekeeping is to provide a clean, convenient work place for employees. This will provide the operator more incentive to maintain a clean elevator by giving him a clean place to work and increasing his morale.

DUST CONTROL SYSTEMS

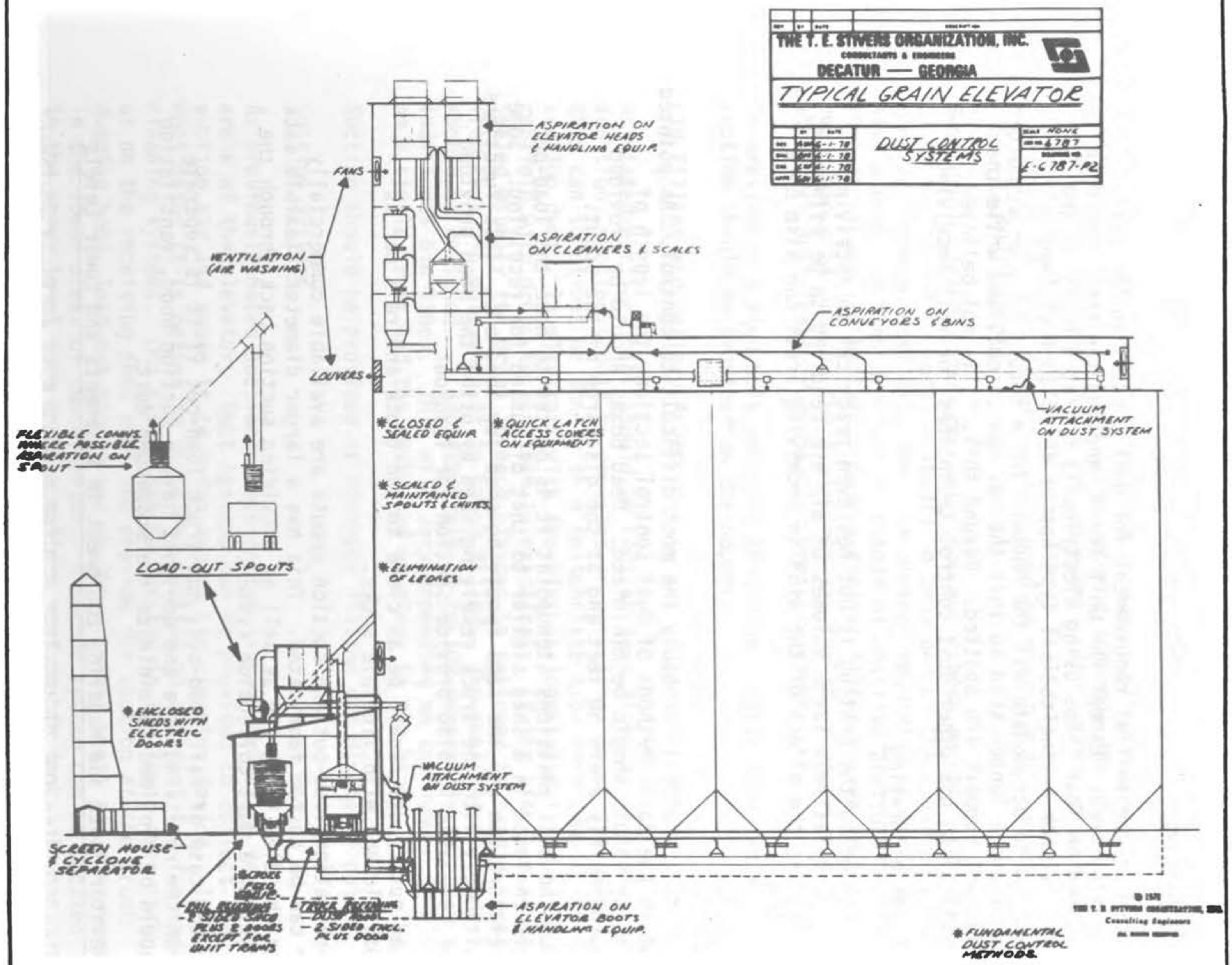
The illustration "Dust Control Systems", on the following page indicates typical dust control systems for grain elevators. The different areas are discussed in the following paragraphs.

Truck Receiving

A typical dust control system would first include providing a shed for the truck dumping area. It is usually practical to enclose the truck dumping area on 3 sides by having a wall on each side of the drive and an electrically operated roll-up door on the third side. The fourth side is where the truck is raised and is open. A curtain can be installed over the fourth side. It can be stationary or adjustable to cut down on the open area and to help minimize dust emissions. With this type arrangement, an overhead hood with a suction system can be installed to collect most of the dust in the enclosure when a truck is being dumped. This is believed to be a practical and reasonable approach to dust control in the truck dumping area.

A similar type arrangement can be used for back-in type unloading hoppers where the third side would simply be enclosed and not have the door.

For hopper bottom truck unloading a two or three sided shed together with choke feed into the receiving hopper is believed to be the only practical control measures that can be applied in this area.



DUST CONTROL SYSTEMS

Rail Receiving

A shed is the initial requirement for dust control in the rail receiving area. Except for unit train handling the shed should be enclosed on four sides using electrically operated doors on the ends. Either a longitudinal type hopper 40 to 50 feet long is required to accomodate all the hoppers for a hopper car, or a shorter hopper and a longer shed so that the car can be enclosed while the different hoppers are spotted. Beyond this, it is not believed practical to use other dust control techniques for rail receiving.

Suction at Grating

Suction below the grating is not believed practical in receiving areas. Relatively large volumes of air are required to be effective. Overcoming the effect of the wind in receiving areas can also be a problem.

Load-Out

This dust source is probably the most difficult to control. As pointed out in the Basic Methods of Dust Control section, the length of gravity spouts should be minimized. Dead boxes should be provided approximately every 50 feet and at the discharge of the spout.

From the dust emissions standpoint it is better to have the load-out area enclosed in a shed similar to that discussed for receiving. Some elevators can use the same receiving shed for load-out. This functions quite well with the truck receiving shed by using the hood provided for receiving to also provide suction for load-out.

Load-out spouts should be as close to the truck and rail car as possible and with flexible socks.

Combination load-out and suction spouts are available commercially or can be custom fabricated. This has a larger diameter flexible sack that handles the grain as well as providing suction back through the spout to a dust collection system.

In the case of rail load-out, and truck load-out if it is separate from the receiving area and does not have a suction hood, ventilation should be provided to minimize the suspended dust.

Elevator Boots and Handling Equipment in Basements and Lower Levels

After applying the fundamental requirements such as enclosed equipment and tight chutes, aspiration or suction, should be considered on elevator boots and at conveyor filling and discharge points. It is believed suction is required in practically all elevators to provide adequate dust control in these areas. The suction system can be routed to a fabric filter in the receiving area.

Elevator Heads and Headhouse Handling Equipment

Again, after providing for the "basic" dust control techniques suction is usually required at elevator discharges and at the filling and discharge points of conveyors. The suction points can be joined together and routed to a fabric filter system. As previously discussed interventing can also be used at elevator discharges.

Cleaning and Weighing

Some grain cleaners require aspiration and others do not. In either case, aspiration or suction should be provided on the cleaning equipment to minimize dust emissions. A cleaner requiring aspiration should have a negative pressure system instead of positive pressure. Therefore it is usually better to have a central filter system in the headhouse area provide the aspiration air for the cleaner. This minimizes dust leaks from position pressure lines.

As previously stated bulk weighers should be intervented. In addition suction should be provided on the hoppers.

Bin Filling and Gallery Areas

As stated earlier, bins should be kept as dust tight as possible. In addition, suction should be provided on each bin. In clustered bins this can sometimes be done with a switchplate type arrangement for the suction duct. In elevators with the bins in longitudinal rows a manifold with drops to each bin is practical. If the bins are tightly sealed usually the drops to each bin can be designed to handle suction from that bin only when it is being filled. The manifold or trunk line should be designed approximately 50 to 100 percent larger than the individual bin lines. This will vary depending on the number of bins on a single trunk and the leaks and openings in the bins.

Suction should be provided at conveyor filling and discharge points.

Suction Systems

As previously noted suction or aspiration is recommended in various areas of the elevator. Duct systems can be provided to collect the suction air and route it to a fan and an air cleaning device. In most cases it is better to route the suction to at least two fan and cleaning systems. One system can be located in the lower area such as on the receiving shed roof and provide for suction at the truck dumping hood, load-out spouts and on the elevator boots and conveyors in the lower areas of the elevator. A second system can be located in the upper level such as on a gallery roof or bin deck. It can provide suction at elevator discharges, weigh hoppers, cleaners, conveyors, and for bin filling.

It appears that in most states fabric filters instead of cyclone type separators are required to meet air pollution requirements. Combination systems of cyclones and fabric filters have been suggested by some people. It is the opinion of the author that the fabric filter system is the most practical approach. This statement is made in light of initial and long range capital costs, power requirements, air pollution requirements and overall operating costs.

FACTORS TO CONSIDER IN DUST SUCTION SYSTEMS

Open Areas

The basic principle of dust suction systems is to provide negative pressure such that dust can be gathered and directed to a certain point. Therefore the air velocity for any open areas must be considered. The formula, Quantity = Velocity x Area (Q = VA), applies here. From the chart below it is noted that relatively small areas require large volumes of air to keep air moving at reasonable dust collection velocities.

Opening Size (Ft.)	Opening Area (Sq.Ft.)	Air Volume Required (Cubic Feet Per Minute)			
		250 FPM (1)	500 FPM	1,000 FPM	2,000 FPM
20 x 20	400	100,000	200,000	400,000	800,000
10 x 10	100	25,000	50,000	100,000	200,000
5 x 5	25	6,250	12,500	25,000	50,000
2 x 2	4	1,000	2,000	4,000	8,000

(1) FPM = Feet Per Minute

From the above chart it can be concluded that open areas can be very critical in dust control systems. Therefore, it is imperative that an open area, whether it be around a truck dumping area or an opening in a conveyor, be minimized as much as possible.

Duct Velocities

Proper duct velocities should be considered in a dust control system. For dust control of grain dusts 3,000 to 4,000 Feet Per Minute is normally adequate.

Volumes and Pressures

The design air volume of a duct or pick-up point must be maintained for a satisfactorily operating suction system. To accomplish this fans must be selected to provide the pressure required for the filter and the duct system. As a general rule most static pressures run higher than initially calculated using accepted design methods. Most systems have static pressure requirements of 10 to 20 inches water gauge.

Without the required static pressure a system will not function satisfactorily. This is probably one of the most improperly handled items in the design of a dust suction system.

Dust Return

Another factor to consider in a dust system is the dust return. The simplest and most practical approach is simply to return the dust to the material from where it came, except where grain is being cleaned and it is desired to remove the dust. To do this the dust will need to be discharged continuously and may require conveying to get it back into the stream of the original material. Where practical the dust should be returned as far downstream from the pick-up points as possible.

It should be noted that much speculation and discussion has occurred in recent months concerning dust return. Some advocate not returning the dust to the grain and disposing of it separately from the grain. It is questionable,that with today's ever tightening requirements for resource and energy conservation and smaller margins, such an approach can be accepted. The elevator operator has bought the dust along with the grain for the same price. Therefore from an economic standpoint he needs to sell the dust. Also most dust in feed grains has acceptable nutritional value.

Elevators that clean grain usually sell the screenings to feed manufacturers. While this may include some of the dust, it usually does not include all of the dust that would be collected in dust control systems. Even if the dust is centrally collected it still must be stored in a bin and eventually handled which is also an explosion hazard.

It should also be noted that dust is continuously generated as grain is handled simply from the attrition of handling it. Therefore a one time removal of the dust will not eliminate dust.

In light of the above points the author believes return of the dust to the grain or for sale as a feed ingredient is the most practical approach.

Air Volumes and Handling Rates

Based on experience, air volumes for bin filling and pick-up points on handling equipment should be in the range of 5 to 10 times the handling rate. The chart below illustrates this.

Handling Rate Bushels/Hour	Air Volume Required Cubic Feet Per Minute	
	At 5 Times Handling Rate	At 10 Times Handling Rate
5,000	500	1,000
10,000	1,000	2,000
20,000	2,000	4,000
40,000	4,000	8,000

Explosion Venting for Filters

If dust filters are enclosed in a building the building should be vented at a ratio of 1 square foot to every 30 to 50 cubic feet of building space. This is in accordance with NFPA 61B recommendations.

To reduce explosion hazards, it is believed that consideration should be given to locating dust filters outside the building. Another approach, if filters are to be housed is to keep them located on roofs or bin decks with explosion relievable enclosures.

Cleaning

A dust suction system can be used for cleaning and housekeeping, as opposed to a separate vacuum system, at a relatively small cost. To do this, entries should be provided along dust suction manifolds with fittings for a flexible hose. The static pressure of the fan on the suction system may have to be increased 2 to 4 inches. Besides capital cost this approach is simple, has lower maintenance cost, and provides a means of handling the dust.

Typical Dust Suction System

To give some idea of a typical dust suction system the following projections are shown. This does not necessarily represent an optimum design, but is shown to give some indication of what might be applied in a grain elevator. The figures are based on an approximate 1 million bushel storage elevator with 10,000 bushels per hour handling systems and truck and rail receiving and load-out as shown in the Dust Control Systems illustration on page 9.

System No. 1 - Lower Level

Suction Air Required	CFM(1)
- Truck Receiving	15,000
- Aspiration on elevator boots and handling equipment.	7,000
- Load-out Spout	8,000
Total	30,000

(1)Cubic feet per minute

Equipment

- Fan - 90" centrifugal for 30,000 CFM at 14 " static pressure (assumed) with 100 horsepower motor.
- Filter - Baghouse type with approximately 2500 square feet of cloth and cleaning apparatus.
- Dust Return Conveyor and Airlock.
- Duct System and Fitting.

(1) Range of Estimated Installed Cost for System No. 1 - $60,000 to $90,000

System No. 2 - Upper Level

Suction Air Required	CFM(1)
- Aspiration on Conveyors and bin filling.	4,000
- Aspiration on Cleaner and Scale.	6,000
- Aspiration at elevator heads and handling equipment	5,000
Total	15,000

(1) Basis 1978 prices for a Midwest U. S. independent grain company. Prices vary widely for different locations, local conditions, labor prices, contractor availability, and owner requirements.

Equipment

- Fan 60" centrifugal for 15,000 CFM at 18" static pressure (assumed) with 75 horsepower motor.
- Filter - Baghouse type with approximately 1500 square feet of cloth and cleaning apparatus.
- Dust Return Conveyor and Airlock.
- Duct System and Fitting.

(1) Range of Estimated Installed Cost for System No. 2 - $40,000 t0 $60,000

Total for Systems No. 1 and 2 - $100,000 - $150,000

VENTILATION ("AIR WASHING")

Any space, including the ambient atmosphere, has suspended dust in it. It is a matter of what size the dust particles are and how many particles are in a given volume.

Likewise, in grain elevators there is always suspended dust present, even with properly applied dust control systems. The amount and size of the dust particles varies depending on the dust sources and the effectiveness of the employed dust control systems. In relatively clean elevators with properly applied dust systems much of this dust will be on the order of 50 microns or less, and probably does not pose an explosion hazard. However it can still be a housekeeping problem as the dust settles and accumulates.

To help eliminate this remaining suspended dust a low pressure ventilation system with fans and louvers can be used. Such a ventilation system, or "air washing" as it is sometimes referred to, will keep the dust particles moving and if properly applied eliminate most of the suspended dust.

The Dust Control Systems illustration on page 9 shows this. It is indicated to be a positive pressure system and includes louvers to exhaust the air. While a negative pressure system would probably be more effective in exhausting the dust laden air it would cause problems with the dust suction systems and have a tendency to remove dust from equipment and spouting. Therefore the positive pressure approach is believed most practical.

(1) Basis 1978 prices for a Midwest U. S. independent grain company. Prices vary widely for different locations, local conditions, labor prices, contractor availability, and owner requirements.

The use of this ventilation system assumes that other primary measures have been taken such that this exhausted dust laden air meets air pollution requirements and good operating practices. It is intended to compliment other dust control systems and not replace them.

It is believed this method may have great application in eliminating suspended dust in confined spaces and decreasing the explosion hazard.

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GRAIN ELEVATOR DUST COLLECTION DESIGN CRITERIA

MAY 30, 1978

Richard I. Marquardt
Vice President
Reg. Professional Engr.
Mn. Lic. No. 3591

CEA.CARTER DAY COMPANY
MINNEAPOLIS, MINNESOTA

The recent rash of grain elevator explosions has focused the attention of many people on a situation which, without knowing all the facts, might lead to the conclusion that the grain industry has been living with this potential hazard for years without taking any steps to minimize the danger. We are not attempting to minimize the hazard nor to indicate that every grain elevator is now equipped with the latest and most sophisticated dust control and air pollution control equipment available but rather that recognition has been given to the problem and steps taken in many elevators to correct it.

New equipment and new dust control methods are being introduced every year. Practices that were in use as little as 5 to 10 years ago are no longer considered practical and are being corrected to conform to changes in grain elevator operations. Dust control equipment manufacturers must and are adapting to these changes also. Methods of disposing of the dust collected in filters are governed by the situation peculiar to each elevator and we must recognize this and provide equipment suited to each problem. In many instances the collected product has considerable value and would constitute financial loss if disposed of improperly. The hazards accompanying handling and re-handling of dust must always be given first consideration. Each of us, in one way or another, has a part in the continued safe operation of all grain operations; wherever located, regardless of the size and only by continued cooperation of all of us will this be accomplished.

Grain elevator dust collection is not a new science or art since there is evidence of such installations having been made many years ago, and, in some cases, still operating. Granted, with the state of the art and limited availability of equipment in those days, the systems would be considered rather crude compared to today's technology, but they served the purpose for which they were intended.

Until the term "air pollution control" began to be used in place of dust control, improvement of internal atmospheric conditions, which generated certain benefits, was of first importance. A differentiation should be made at this point between dust control and dust collection. Dust collection, which will be discussed in this paper, refers to the control of dust emission from specific sources whereas dust control infers complete elimination of dust. Air pollution control is generally thought of in terms of the outside atmosphere. There are many reasons why dust collection systems are installed, some of which are:

1. Improvement of internal atmospheric conditions which improves employee morale and reduces labor turnover.
2. Reduction in personnel accidents.
3. Maintenance costs are reduced.
4. Reduction in rodent and insect population.
5. Insurance rates are reduced.

A dust collection system comprises many integral parts which will be discussed later, and may be briefly described as "a means of controlling the air movement around a dust producing source so as to reduce as far possible the emission of dust particles to the surrounding atmosphere".

This is accomplished by means of hoods or canopies placed over these areas and connected to a fan which creates the necessary air flow into the hood, carrying dust particles with it.

The size and design of specific hoods is dictated by the area where the dust is created, the grain handling capacity of the equipment involved, available space to locate a hood and desired face velocity of the air as it enters the hood. The grain handling equipment in typical elevators, while similar in many respects,varies enough from one location to another such that the hoods are usually designed and fabricated to suit each location. There is little published data on the specifics of grain elevator dust collection design and in most cases it is necessary to follow parameters and data accumulated over many years of installing such systems.

In general, however, a hood or canopy must, first of all, enclose the dust source as much as possible keeping the open area as small as possible which in turn reduces the total air requirements and thus the total connected HP. There are a number of dust producing sources in a typical grain elevator. Any time the grain stream is re-directed, dropped from or into a bin, box car or truck, dust is created. Each of these sources requires a different approach in determining the amount of air required for efficient dust collection and the proper design and location of the hoods to capture the dust. It would be well to point out that installing a dust collection system does not mean that the atmosphere will be completely dust-free since there are situations in the handling of the grain within the elevator which do not lend themselves to complete control with the state of the art as it is today. Since it is not practical to provide a separate fan and dust collector for each dust source, a number of hoods are connected by means of duct work to a single fan and collector. The layout of the duct work is usually made to suit available space within the elevator and sized to keep the air veolicty high enough to prevent settling of the dust particles. There are published manuals which can be referred to in determining the proper duct sizes.

Dust collection systems installed for instance up to 25 years ago utilized dust collectors referred to as "cyclones". They are a mechanical type of dust separator which relies on cyclonic action (hence the name cyclone) within a chamber to separate by centrifugal force a certain percent of the dust from the air stream. They are not 100% efficient which means a certain amount of the dust escapes to the atmosphere. Cloth type dust filters have been available for many years but their design did not at that time lend themselves to application to grain elevator dust control. The original models consisted of a series of cloth tubes arranged inside of a sheet metal housing. The air passed thru the cloth, leaving most of the dust on the inside (similar to vacuum cleaners). Cleaning consisted of shutting the system down and rapping the tubes to disloge the dust.

There were a number of factors which prevented this type of filter from being utilized to any great degree in the grain industry. First, they required a considerable amount of space for installation. Secondly, they did not lend themselves to dust disposal as readily as a cyclone but perhaps the most important fact was that the dust system had to be shut down in order to dislodge the dust. If the tubes were not cleaned periodically, the effectiveness of the dust collection system would be lost.

A newer reverse jet cleaning designed dust filter also employs a series of tubes in a sheet metal housing but, in addition, having an integral continuous cleaning mechanism for cleaning the filter tubes while the dust system is in operation. This new design has made possible their incorporation in dust collection systems which must operate continuously for sustained periods of time and where it is not possible to shut the system down for cleaning the filter tubes. The selection of the correct size and type of filter thus becomes a very important factor. The design criteria would involve, of course, the total CFM in the system, anticipated dust loading, type of dust and atmospheric conditions anticipated. All these factors will have to be considered when making a selection, keeping in mind the need for continuous operation. Anyone having previous experience of application of filters in grain elevators under similar conditions will be aware of the need for careful selection.

To this point I have attempted to briefly describe how a dust collection system functions, what the major equipment items consist of and what parameters are used in design. As mentioned previously, there is a lack of published information on the specifics of dust collection systems in grain elevator dust control and the information which is available refers primarily to the need for dust collection at specific areas without going into any detail as to how this is to be accomplished. There are, of course,many manuals available that refer specifically to ventilation problems as opposed to dust collection.

With this thought in mind, the initial approach to installation of a dust collecting system would be contact with a firm which has evidenced by past experience its capabilities in this field. This means a working knowedge of how a grain elevator operates and familiarity with problems peculiar to this industry which will affect the overall design. They should be prepared to make a detailed and in depth survey of the complete elevator to ascertain where the dust sources are or likely to be, how to contain the dust, the approximate location of the duct work so as not to interfere with the elevator operations, where the major equipment items such as fans, and dust filters, are to be located, keeping in mind the need for easy access for maintenance, and how to dispose of the dust.

The first phase as outlined above requires a specific expertise which can only be obtained by a number of years of experience in working with this industry. The second phase involves the preparation of engineering drawings which puts down on paper the complete details of what is to be furnished. Again, this requires a knowledge of grain elevator operations so that the selected equipment is compatible with other existing equipment and the proper functioning of the elevator. The third phase involves actual installation of the equipment and must be considered as being a critical part of the final operation of the system. As previously pointed out, the exact design and location of the dust collecting hoods is normally estimated from field measurements and must be compatible with other elevator equipment; therefore, there must be continual communication between the installer, the draftsman and the engineer. Improperly sized or designed hoods can drastically reduce the effectiveness of a dust collection system.

After the installation is completed and before being turned over to the owner, the design engineer should go over the complete system with the assigned elevator maintenance personnel to familiarize them with the operation. They should be instructed on how to detect the initiation of potential problems and how to correct them before they become major. Of primary importance, he will instruct them in the proper maintenance procedure to insure the system maintains its original effectiveness.

The last phase involves the actual procedure in keeping the system functioning properly. It is recommended specific individuals be assigned by the owner whose duties would include complete familiarization with the system drawings, all maintenance manuals referring to specific items of equipment and be responsible for keeping spare parts readily available. This function cannot be emphasized too strongly since today's air pollution control equipment has become very sophisticated and an understanding of the basic rudiments of air handling and fan and filter selection criteria for proper sizing, plus a thorough understanding of how the equipment functions should be of prime importance for whomever is assigned. The equipment manufacturer will provide this initial training.

To sum up, efficient dust collection is only one step towards reducing the possibility of a dust explosion. There are many other guidelines which must be followed, most of which are outlined in publications of the National Board of Fire Underwriters or Insurance Underwriters or the insurers themselves. In the initial part of this paper a statement is made that a dust collection system reduces, not eliminates, the emission of dust particles to the atmosphere and small sub-micron particles, in most cases invisible to the naked eye, are always present. While we as an equipment manufacturer do not at the same time profess a knowledge of the exact details of what causes a dust explosion or the resultant effects, it is common knowledge that for an explosion to occur there must be three things; dust, a source of oxygen and a source of ignition. A good dust collecting system assists in controlling the first factor.

INSTRUMENTATION AND SENSORS

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INSTRUMENTATION AND SENSORS

I. INTRODUCTION

The subject of this paper, as the title suggests, is Instrumentation and Sensors, as they relate to causes and prevention of grain dust explosions.

We will first examine the properties of a grain dust atmosphere (e.g. dust concentration, particle size, chemical composition, moisture content, temperature, humidity) which combine to create an explosible atmosphere. The role of each characteristic is described in terms of the basic explosion process. Most likely sources of ignition are identified and the effects of static dust accumulations are outlined. -- The concept of "critical points", or "critical locations", in a grain elevator is proposed, instruments and sensors for both periodic and continuous monitoring are described by type, and the concept of a central early-warning system is developed. Such a system is completely practical in present-day technology and can signal the early onset of potentially explosive conditions, well before explosive conditions are reached; alarms can be automatically triggered and preventive equipment actions can be automatically initiated.

By way of introducing this subject to any other audience, one would begin with a review of the terrible tragedies caused by grain dust explosions, particularly the very large ones of the past two years, which underscore the importance of this subject and the need for preventive measures. One would discuss some of the statistics of grain dust explosions, the nature and extent of the loss of life and property damage which has occurred, the concerns of both management and labor in the grain industry, concerns of USDA, OSHA, and other government organizations. Here, however, we have the opportunity to hear all this first-hand, to hear all possible perspectives as to the present status and future needs of the industry with respect to its explosion hazards. This symposium represents an unparalleled opportunity for the exchange of ideas on all aspects of this problem, so without further ado I will proceed to the subject at hand, pausing only to introduce the subject of instrumentation and sensors with two important fundamental points:

(1) The easiest and least expensive way to make an existing grain elevator safe against explosions is to install and maintain an early warning system and, simultaneously, institute operational policies and procedures which will assure good housekeeping, good maintenance, and good safety practices throughout the plant.

(2) Sophisticated technology, such as is employed in present-day sensors, instruments, and systems, including computer technology, is not to be shied away from, but is to be actively and aggressively brought to bear to serve the grain industry and the national interest in this important national problem. Sophisticated instrumentation _can_ be made rugged and reliable, it _can_ be designed for easy operation and maintenance; the grain industry need only insist on these features in order to have all relevant aspects of modern technology at its service.

II. CONDITIONS REQUIRED FOR GRAIN DUST EXPLOSIONS

Beginning with the well-known "fire triangle", translated to grain dust explosions in Figure 1, we state the three conditions required for a grain dust explosion to occur, as follows:

(1) Grain dust must be present in a concentration within the explosible range (exceeding the Minimum Explosible Concentration (MEC)) which, in turn, is determined by composition, size distribution, and other properties of the grain dust particles.

(2) The dust must be dispersed in an oxidizing atmosphere, and the oxygen concentration must be sufficient so that a rapid combustion process (explosion) can be initiated and sustained.

(3) An ignition source of sufficient energy and duration must be present to initiate the explosion.

Condition (2) is essentially always met, since air is always present in grain elevators and storage operations. (Inerting, i.e. replacement of some of the air by an inert gas, is important as a local fire or explosion suppression technique, but it is not applicable on a continuing basis in large or open areas.)

Conditions (1) and (3), or both, must therefore be eliminated if grain dust explosions are to be prevented. Clearly, it is important that every effort be made to eliminate both ignition sources and explosible atmospheres in grain elevators.

The sensors and instrumentation we will discuss will deal with both of these sides of the explosion triangle, though most importantly with the grain dust atmosphere and its properties.

A fourth condition is sometimes included in the list of explosion conditions: that the dust cloud must be in an enclosed or confined space. If the dust cloud is in an enclosed space, the pressure built up by the explosion will be increased, thereby increasing damage to the structure and any objects present. Further, the probability for build-up of dust concentrations exceeding the MEC is much higher when dust is generated in an enclosed space, thereby also increasing the probability of occurrence of explosions as well as the magnitude of damage when an explosion does occur. An enclosed space is not required, however, for detonation or deflagration to take place.

III. BASIC PROPERTIES OF EXPLOSIVE DUST ATMOSPHERES

To specify logically the properties of dust atmospheres which should be monitored, consider a dust cloud represented schematically by spherical particles of various sizes separated by various distances, as shown in Figure 2. Now, assume that one or more of these particles has ignited and is burning. -- If the combustion process is to propagate, enough heat must be generated and transmitted to nearby particles to raise their temperatures beyond the ignition temperature and to provide sufficient energy for them to ignite.

This simple qualitative statement (last sentence in preceding paragraph), carefully analyzed, provides complete identification of the parameters of importance:

(1) Particle size. The heat generated by a particle depends on its size. In addition, the combustion rate depends on particle size. In a dust cloud, therefore, the Minimum Ignition Energy (MIE) and Minimum Explosible Concentration (MEC) depend on the particle size distribution, both of these being lower for smaller particles. Figure 3 shows these effects.

(2) Dust concentration. The number, or mass, of particles per unit volume in a dust cloud will determine the distance between a burning particle and an unburned particle in our simple model (Figure 2). The higher the concentration, the smaller this distance will be, the more heat energy will be transmitted to the unburned particle, the higher temperature it will reach, and the greater the probability will be that the minimum ignition temperature and energy will be exceeded in the unburned particle. In short, the higher the concentration, the more efficient is heat transfer, and therefore combustion propagation, from one particle to another.

(3) Particle composition. It is the chemical composition of the particles, coupled with properties of the combustion reaction for those molecules which are present, which determines the minimum ignition temperature and the minimum ignition energy of the dust. -- A simple way of looking at this point is to consider the progress of a reaction from left to right in the energy diagram shown in Figure 4. Here we plot schematically the energy of the system versus band-length, or progress of the reaction, from left to right. We can imagine the initial stable system consisting of the mixture of organic molecules present in the particle and oxygen molecules present in the air. This system will remain stable in the bottom of the left-hand well, unless sufficient energy is supplied to the system to raise it above the threshold, called the activation energy E_A, whereupon the reaction can proceed toward the right-hand well, thereby producing reaction products such as CO_2, H_2O, and other residuals. The net energy release, E_R, is called the heat of combustion and is the heat released in the chemical reaction (combustion); the activation energy, E_A, is the threshold energy required for combustion of the original molecules.

A particle of grain dust will contain many types of molecules with various heats of combustion. Values for some of the amino acids, for example, range from about 230 kcal/mole to about 1200 kcal/mole. These compare with values for nitroglycerin and trinitrotoluene (TNT) of 332 and 821 kcal/mole, respectively.

(4) Moisture content of grain dust particles. The importance of this parameter is seen best in the context of the foregoing items (2) and (3). Moisture, i.e. H_2O, is very stable and is nonreactive. As a constituent of the particles it therefore inhibits combustion, thereby raising the amount of heat required for combustion to proceed. We may think of the heating and burning process as follows: as long as water is present in the particle, heat energy applied to the particle must be used to raise the temperature of both the grain constituents and the moisture constituent; when the boiling point of water is reached, additional heat energy will be used to convert the moisture into vapor and to drive the vapor from the particle; additional heat energy will then continue to raise the temperature of the grain constituents, eventually to ignition. -- Thus we see that moisture content in grain has two effects, first to raise the minimum ignition energy, and second to raise the minimum explosible concentration (since more efficient heat transfer is needed). Figure 5 shows both of these effects; it is interesting that the minimum explosible concentration seems to increase linearly with moisture content, while the minimum ignition energy does not change much until the moisture content is greater than 0.1 gms/liter where it begins to increase quite rapidly.

(5) Ambient temperature. Figure 6 shows the effect of temperature on minimum ignition energy for various coals. As ambient temperature increases, minimum ignition energy decreases rapidly and substantially. Still, it may have only secondary direct importance, in that this temperature range is relatively restricted and the ignition energy (for coal) seems to remain relatively high even up to 45°C (113°F). Data are, of course, needed on this effect for grain dust specifically. - Ambient temperature may, however, be very important in its relation to atmospheric humidity and absolute moisture content of the air. We will discuss this in Item 6. The physical basis for the direct ambient temperature effect is that as ambient temperature increases, the system in the left-hand well (Figure 4) rises to an increased energy up in the well, so that the additional energy (activation energy, related to minimum ignition energy) required to overcome the barrier to combustion is reduced.

(6) Humidity. This parameter, because of recent USDA procedural regulations based on it, has become quite controversial. Let us look at the physical basis for the importance it may have:

First, for dust which is suspended in the atmosphere a sufficient length of time, an equilibrium is established between the moisture content of the grain dust particles and the humidity of the atmosphere; this equilibrium is determined simply by the equality of the vapor pressure due to moisture in the grain particle and that of the water vapor in the atmosphere. The higher the humidity of the air, the higher the grain dust moisture content is likely to be.

Second, water vapor in the atmosphere increases its heat conductivity; this could improve heat transfer from one particle to another in grain dust combustion, but the quantitative importance of this effect is not known at present.

Third, water vapor in the atmosphere increases its electrical conductivity. This point is very important in connection with the possibility that static electricity is an important ignition source in grain elevators. Static charge accumulating on any surface or object will leak away more rapidly in a more conductive (moist) atmosphere than in a less conductive (dryer) atmosphere.

Quantitatively, the overall effect of humidity is not known, though the first and third points are qualitatively understood and acknowledged to be very important. Specific data on humidity effects are clearly needed.

A final point: In all three effects absolute humidity, rather than relative humidity, is the important physical variable. To illustrate: A relative humidity of 100% (saturated air), corresponds to 4.8 grams per cubic meter of water vapor at 0°C (32°F), and to 39.2 grams per cubic meter at 35°C (95°F), more than 8 times the 0°C value. Now applying this to Figure 4, we see that the Minimum Explosible Concentration (MEC) for cornstarch is 4 times greater at 35°C (a summer day) than it is at 0° (a winter day), even though the relative humidity is the same in both cases. Figure 6 is included here for reference and shows the mass of water vapor in air as a function of temperature for various relative humidities.

These six physical properties of grain dust atmospheres, then, suggest themselves for monitoring and surveillance. Each must be treated differently, and I would suggest the following approach, based on very practical considerations: (1) dust concentration (grams/meter^3) should be monitored at all locations in an elevator where high dust concentrations can be formed, i.e. the "critical points" in the elevator. (2) Baseline data should be obtained on particle size distributions at various locations in an elevator, for the various types of grain processed by the elevator. Then, where the mass-mean-diameter of particle sizes is smallest and where dust concentration is highest, the particle size distribution should be checked periodically, and whenever there is a change in the type of grain being handled. (After some experience, the frequency of these measurements can probably be reduced.) (3) The moisture of grain dust particles should be monitored at the location(s) where moisture content is lowest. Baseline data may be required to determine these locations. (4) Ambient temperature and humidity should be measured at a few typical points in the elevator, but probably need not be monitored at all high-dust-concentration locations. -- It would be useful to monitor temperature and humidity outdoors near an elevator for comparison with values obtained inside the elevator, to look for correlations which might possibly be applied to historical data on explosions.

IV. SENSORS FOR POTENTIALLY EXPLOSIVE DUST ATMOSPHERES

Having identified the important parameters to be monitored in potentially explosive dust atmospheres, we now consider the methods employed and equipment available to carry out the measurements.

Dust particle concentration. This parameter, coupled with particle size distribution, is properly deemed to be a most important parameter in the composition of an explosible dust atmosphere. Minimum explosible concentrations for grain dusts are reported in the range from 20 to 100 g/m^3, and instrumentation should be capable of valid measurements up to concentrations of about 50 g/m^3. In addition, continuous *in situ* monitoring is necessary in order to follow real time variations in concentration.

Numerous instruments are available on the market for measuring dust concentration; however, most of them employ extractive sampling with subsequent analysis in the instrument. Examples include several beta gauge units, in which a sample is pumped into the instrument, deposited on a tape collector, then analyzed by means of beta-ray transmission. A second example is the hi-volume sampler, in which a measured amount of air is drawn into the instrument through a filter, a dust sample is collected on the filter, then analyzed by weight later in a laboratory. Aside from the fact that such monitors do not provide continuous measurements, they are troubled by errors which occur in any extractive sampling method. In particular, losses occur on the walls of the tubing or piping required in extraction, and collection efficiency varies with particle size.

Of all instruments available for dust concentration measurements, only two types provide continuous *in situ* measurement. These are both optical instruments, one based on light back-scattering and one based on light transmission or opacity. Of these, only the light back-scattering instrument can accomodate the range of concentration measurements required. A schematic diagram of such a back-scattering apparatus is shown in Figure 8. Figure 9 shows the housing for the optical components; note from the optics diagram in Figure 8 that the sampling volume is external to the instrument, so that particles are measured just as they occur in the atmosphere. This concept in its application to particulate mass concentration measurements is patented by ESC and is currently used primarily in environmental applications. The device is expected to be readily adaptable to grain dust measurements, however, and we are proposing to carry out this adaptation.

Particle size distributions. Here again, there are a number of types of instruments on the market for measuring particle size distributions, they do not all operate in the range required in grain dust applications. Of those which do, three types may be considered.

The first is the simple filter collection of dust samples, with subsequent microscopic or electron-microscopic analysis. The apparatus required for sample collection is rather simple, but analysis of the samples is labor-intensive and is correspondingly expensive. On the other hand, best accuracies are obtained by this method.

A second method involves light scattering and may employ either laser light or other usual light sources. Some currently available instruments employ extractive sampling, in which particles are transferred from the atmosphere through a tube, and into a sampling volume where the light scattering occurs; others involve light scattering measurements *in situ* where particles are examined as they are in the atmosphere. Here again, it is important to avoid the distortions and errors which occur in transport systems; therefore, the *in situ* light scattering instruments are much to be preferred.

A word about distortions and errors in transport systems: Fine particles, say less than about 5 microns in diameter, generally follow the streamlines of airflow. Larger particles, say greater than 10 microns in diameter, because of their larger inertia, do not follow streamlines as well and some are deposited on walls, bends, and other parts of the transfer apparatus. The efficiency of collection for a transport system, therefore, varies with particle size and type, resulting in great uncertainties when the particles to be analyzed are large and of unknown or variable particle size distributions.

A third method, namely cyclone separation, makes use of these very effects. Cyclones seem to be adequate for many applications and may serve well here.

Dust particle composition. Generally, the composition of the dust particles should be the same as that of the grain being processed, except for moisture content.

Moisture content of dust particles. Grain dust particles, in contrast with bulk grains, are small and moisture in them probably evaporates rather quickly to a moisture content which represents equilibrium with atmospheric humidity. This statement is speculative at this time; however, if it can be shown to be true, then equivalent information will be contained in data on moisture content of grain dust particles and in data on atmospheric humidity. Both should be monitored in early test programs and correlation data should be obtained.

To monitor moisture content of grain dust, the same principle might be used as is used in standard instruments for grading grain as to moisture content. The precision and accuracy typical of those measurements are not required, however, for this purpose. Simplified versions, also involving IR reflectance, can therefore be employed; to our knowledge, there is only one such simplified version on the market.

Ambient temperature. Many sensors are available for temperature measurement; most suitable for this purpose are various thermocouples and thermistors. The accuracy requirement is not great, perhaps ±1°C. Numerous temperature sensors are required in a proposed central early warning system; several types are available, and they are relatively inexpensive.

Humidity. Humidity measurements in a high-dust-concentration environment are extremely difficult, and we know of no instrument that is suitable for such measurement either of relative humidity or absolute humidity. A possibility for future development, however, is that infrared techniques, perhaps involving spectroscopy, might be applied to this problem. Since we wish to determine water vapor in the atmosphere, IR absorption or transmission measurements would likely be required, in contrast with reflectance as is used in moisture determination in grain.

In general, outputs from all of the above sensors are analog current or voltage signals. These signals can be conditioned and fed into analog-to-digital converters or multiplexers for digitization and subsequent handling in data processing or computer equipment. (Refer. Section VII.)

V. MOST PROBABLE IGNITION SOURCES AND RELATED SENSORS

Ignition sources responsible for explosions in grain elevators can, according to Palmer, conveniently be grouped as follows: (1) Welding and cutting, (2) Flames other than welding, (3) Glowing combustion and smoldering, (4) Spontaneous heating, (5) Hot surfaces, (6) Sparks -- from friction and impact and from electrical breakdown, and (7) static electricity.

This list is, by now, quite familiar to all of us. It is included here for completeness and for consideration as we envision a monitoring system for the alarm of potentially dangerous situations in an elevator. We will consider each of these source groups, together with the possibility of sensors, monitoring, and advance warning of possible explosion ignition.

Welding and cutting. Welding and cutting are characterized by small flames and very high temperatures. If not closely controlled, generally by entrance and permit procedures, welding can occur anywhere at almost anytime. Therefore, the likelihood of preventing an explosion, once welding begins in an explosible dust amosphere, is very low. -- Since this ignition source appears suddenly and without warning, there is nothing we can sense or measure which indicates it is about to take place. Thus, there are only two ways to prevent explosions ignited by welding and cutting: (1) prevent explosible dust atmospheres, and (2) institute and enforce tight entrance and permit procedures for welding, including cleanliness standards for areas where welding is to take place.

Flames other than welding. This category generally encompasses smoking, matches, flames fanned from smoldering dust piles, etc. Here again, the human origin of flames is unpredictable, and the same comments apply as for welding and cutting. Flames caused by fanned smoldering dust or other non-flame combustion are also unpredictable, but since they are preceded by a combustion process, that combustion process may be detected and appropriate action taken to prevent further smoldering and flames.

Glowing combustion and smoldering. These are combustion processes proceeding slowly, i.e. not rapidly enough to produce flaming. Nevertheless, the combustion process produces the usual products, which may be detected with suitable sensors and instruments. The usual combustion products are, of course, CO_2, H_2O, CH_4, CO, fine particulates, and other residuals. Many smoke (fine-particle) detectors are on the market, particularly for home use; however, they are not suitable for use in a grain elevator, where the usual environment is dusty and variable, so that the small incremental amount of fine particulate matter produced by slow combustion cannot be detected reliably. -- Therefore, it appears most promising to monitor CO or CO_2. Several instruments and sensors are available commercially. One operates on the principle of infrared absorption. Another operates on the change in resistivity of a tin oxide semiconductor when combustion gases are absorbed onto its surface. These devices, and possibly other candidate sensors, should be tested in grain elevators, particularly to determine whether interferences occur with other gaseous constituents normally present in grain elevator atmospheres.

Spontaneous heating. This generally refers to the spontaneous heating of grain piles or stored grain, due to bacterial activity. Hot-spot detectors have long been on the market to monitor this phenomenon. They should be adequate and can serve well as part of our system approach to monitoring, alarm, and prevention.

Hot surfaces. These include surfaces which become overheated because of overloaded motors, bearings insufficiently lubricated or clogged, etc. Also included are the hot surfaces produced when a choked leg occurs, or when a belt slips. -- It should be possible, though considerable effort may be required, to identify such surfaces which may become overheated in an elevator. It would be a relatively simple and inexpensive matter, then, to attach a thermocouple to these surfaces, of course assuring good thermal contact. Overheating would then get an operator's attention almost as soon as it occurs, so that appropriate repairs can be made. Similarly, belt slow-down detectors should continue to be used to signal belt slippage or other problems or hazards.

Sparks from friction, impact, and electrical breakdown. These again are relatively unpredictable phenomena. As such, advance warning is difficult or impossible; therefore, the best prevention lies in good maintenance, good housekeeping, and good safety practices. -- A serious problem in this category occurs when parts of the bucket elevator strike against metal framing or against the elevator enclosure. Since dust concentrations can be very high within the enclosure, it is imperative that the bucket elevator operate properly and that the installation be properly designed and maintained, so that metal-on-metal contact is not made and sparks are not generated. -- If it were worthwhile, spark detectors could no doubt be developed, using rf, optical, or other techniques. The usefulness and cost effectiveness of such detectors, however, seem questionable.

Static electricity. Static charge build-up occurs whenever dissimilar materials come in contact with each other. This charge may leak away harmlessly if the object on which it is accumulated is conducting and is connected to ground by a conducting path. If the object is conducting, but insulated from conducting paths, the charge will build up, distribute itself according to the size and shape of the object, then leak away only as conducting paths become available, e.g. through atmospheric humidity or, more dangerously, through the approach of a conductor at say ground potential, whereupon a spark can be generated. If the object on which charge is built up is an insulator, the charge may well remain localized for an extended period of time. On a PVC belt, for example, the charge can be localized on the belt and transferred, virtually intact, to another point where, if a conductor is in close proximity to the belt, it can be partially or all removed, thereby transferring charge to the second conductor. (This procedure is, in fact, used in nuclear particle accelerators to generate voltages of 1 to 12 million volts fairly routinely, under closely controlled conditions of course.)

It is desirable to monitor static voltage in a grain elevator, to evaluate the magnitude of static voltages built up and to determine the potential hazard. This should be done, at least for some period of time, to establish the expected anti-correlation between static voltage build-up and humidity. Also, the degree of the problem should be ascertained and, if necessary, corrective action (e.g. grounding) should be implemented.

Static monitors generally operate on an electrometer principle and are difficult to use quantitatively. However, some commercially-available instruments are able to read static voltages up to 200,000 volts or more; these could be useful in a monitoring system, at least until extended operating data are obtained. A precaution that every elevator operator can and should take is to be sure that all elements of the elevator, all parts of the plant, are grounded; this will assure that no sparks occur between structural components of an elevator, this being a particularly unnecessary occurrence and safety hazard.

VI. STATIC DUST ACCUMULATION AND RELATED SENSORS

The importance of static dust accumulations is two-fold:

(1) Smoldering fires can start in accumulated static dust piles; these in turn can fan into flames and become significant ignition sources.

(2) If a single small explosion occurs somewhere in an elevator, the pressure wave will kick up static dust accumulations into the atmosphere as it travels through the elevator, thereby creating explosible mixtures which in turn can ignite, causing additional explosions to occur. If the initial explosion is sizeable it will cause a shock wave to propogate through the elevator; static dust will be kicked into the atmosphere, and the high pressures and temperatures will ignite the dust clouds thus formed.

Clearly, the best prevention against dangers of static dust accumulations is to avoid the accumulations, i.e. by good dust collection methods and good housekeeping practices. Note that relatively small accumulations of static dust (less than ¼" thick) can cause explosible mixtures to be formed when this dust is kicked up into the air above the floor.

It is possible to assemble a sensor to monitor the thickness of accumulated static dust layers. Such a sensor would consist of a beta-ray or soft gamma-ray source and detector; the attenuation of the radiation through the accumulated dust layer would then indicate the layer thickness. Such a device could be placed on a pedestal or at a point in the plant where it would remain relatively undisturbed by people or equipment. Its primary disadvantage is that it would be subject to tampering.

This is an item which can be evaluated; it is relative simple technically, though some packaging problems must be solved. Evaluation by elevator superintendents is required to determine the degree of its usefulness.

VII. THE CONCEPT OF "CRITICAL POINTS" IN A GRAIN ELEVATOR, EARLY WARNING SYSTEM

Since it is impossible to monitor the properties of potentially explosive grain dust atmospheres at all points throughout a grain elevator, we must identify the "critical points", or "critical locations", where monitoring is to be done. These should be locations at which dust concentration is highest and where other properties constituting explosibility are more favorable to explosion than anywhere else in the elevator.

The principle here is that if there is no problem signaled at any of the "critical locations", then there should be no problem anywhere else in the elevator.

This concept of critical locations is not new, having been proposed in 1964. Figure 10 shows the critical locations in a medium-size terminal elevator, as proposed at that time. I believe we would agree that, for the most part, these are still the "critical locations" in existing elevators.

Basically, the locations indicated are the grain transfer points and locations at which dust clouds are likely to accumulate, as follows:

(1) short tunnel from truck dump or car dump to basement of elevator
(2) basement of elevator
(3) elevator head
(4) distribution floor
(5) scale floor
(6) gallery, or Texas house, near the movable tripper
(7) tunnel under storage bins
(8) elevator legs, inside bucket elevator enclosures

These are the areas where dust clouds are most likely to form and where dust concentration is likely to be highest in the elevator. Therefore, a continuous monitoring system for early warning of explosive conditions should include dust concentration monitors, and possibly temperature sensors, at these locations. Certainly, the number required and their precise locations will depend on the specific elevator and its configuration; in some cases not all of the above locations will require monitors, in others perhaps additional locations should be monitored.

To continue with the idea of a central early warning system, we may appropriately ask what sensors are required to make this concept viable. In line with the previous sections of this paper, the following sensors are proposed:

- .humidity sensors, located at a few typical points in the elevator
- .sensor for dust moisture content, rotated among several locations, to obtain baseline data
- .combustion gas detectors, located at nor near each of the above dust cloud areas and in areas where fires are likely to occur
- .temperature sensors on motor housings and bearings, to detect overheating
- .belt slow-down detectors
- .hot spot detectors in bins
- .electric field detector, for measurement of static voltage build-up, in elevator leg and other high-static-potential areas

As previously indicated, each system would be designed and tailored for the particular elevator in which it is to be installed. The components of each system, however, are standard; the number and types of sensors would be chosen according to the particular system design.

A typical system configuration is shown in Figure 11. This shows, schematically, that any number of sensors can be fed into an appropriate number of multiplexers (16 channels each in this example), then these are fed over a simple twisted wire-pair to multiplexer receivers (64 channels each in this example), following which the data are transmitted to the chentral data acquisition system, processor, or computer. At this point, data are compared with limits and/or instructions appropriate to each sensor. As required, output signals, not shown, are generated to trigger alarms, equipment status changes, and any other actions programmed into the system.

Concluding this section, I want to emphasize that a system of this kind can be adapted to elevators of any size. Preliminary cost estimates indicate that the cost will be one to a few percent of the total cost of the elevator. To reiterate a point made in the Introduction: Use of such a system could be the most effective and economical way to make existing grain elevators safe against explosions.

FIGURE 1 "Dust Explosion Triangle," Translated from Well-Known Fire Triangle.

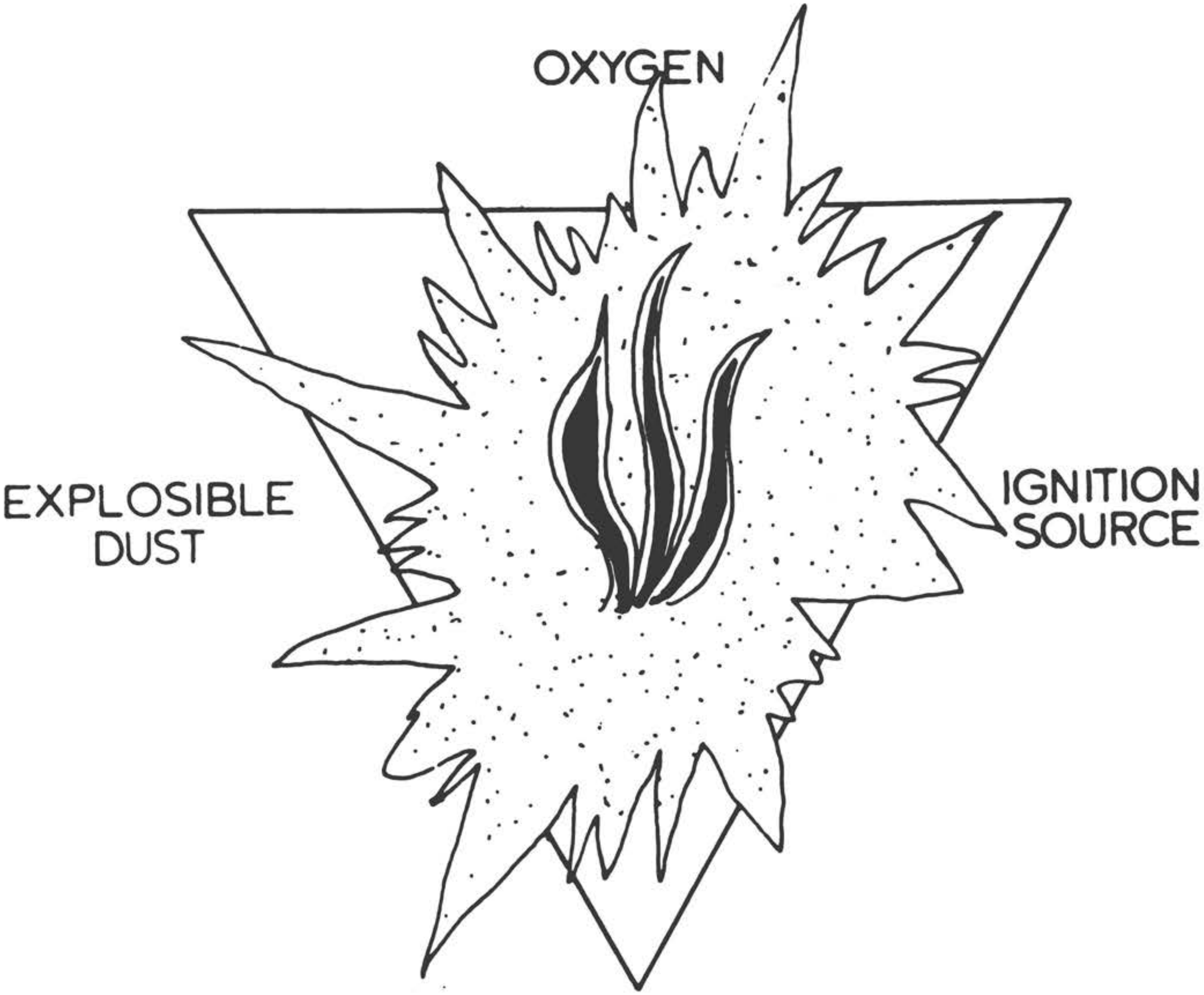


FIGURE 2 Schematic Representation of Dust Particles (enlarged).

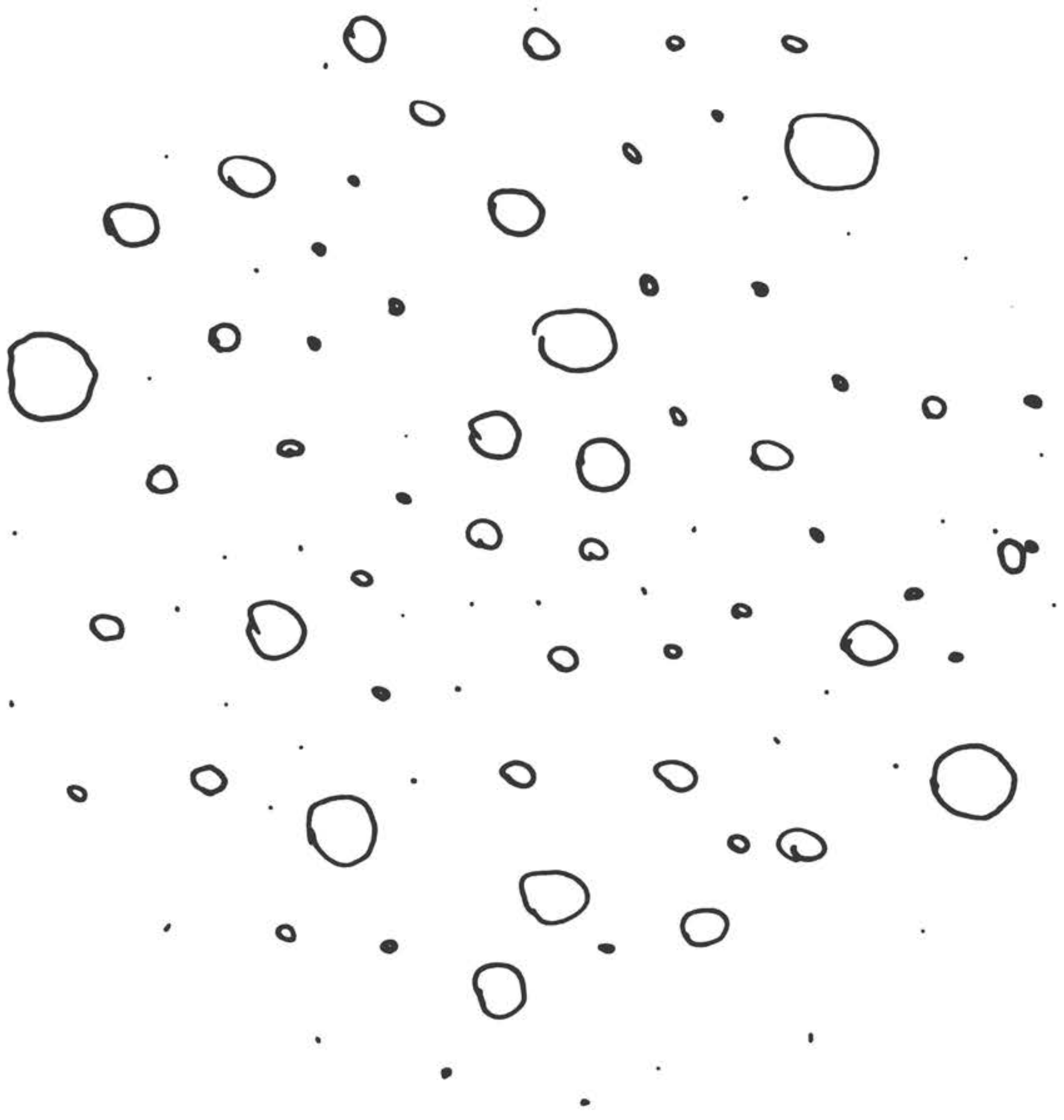


FIGURE 3 Minimum Ignition Energy (MIE) and Minimum Explosible Concentration (MEC) vs. Particle Diameter for Cornstarch (Ref. 3).

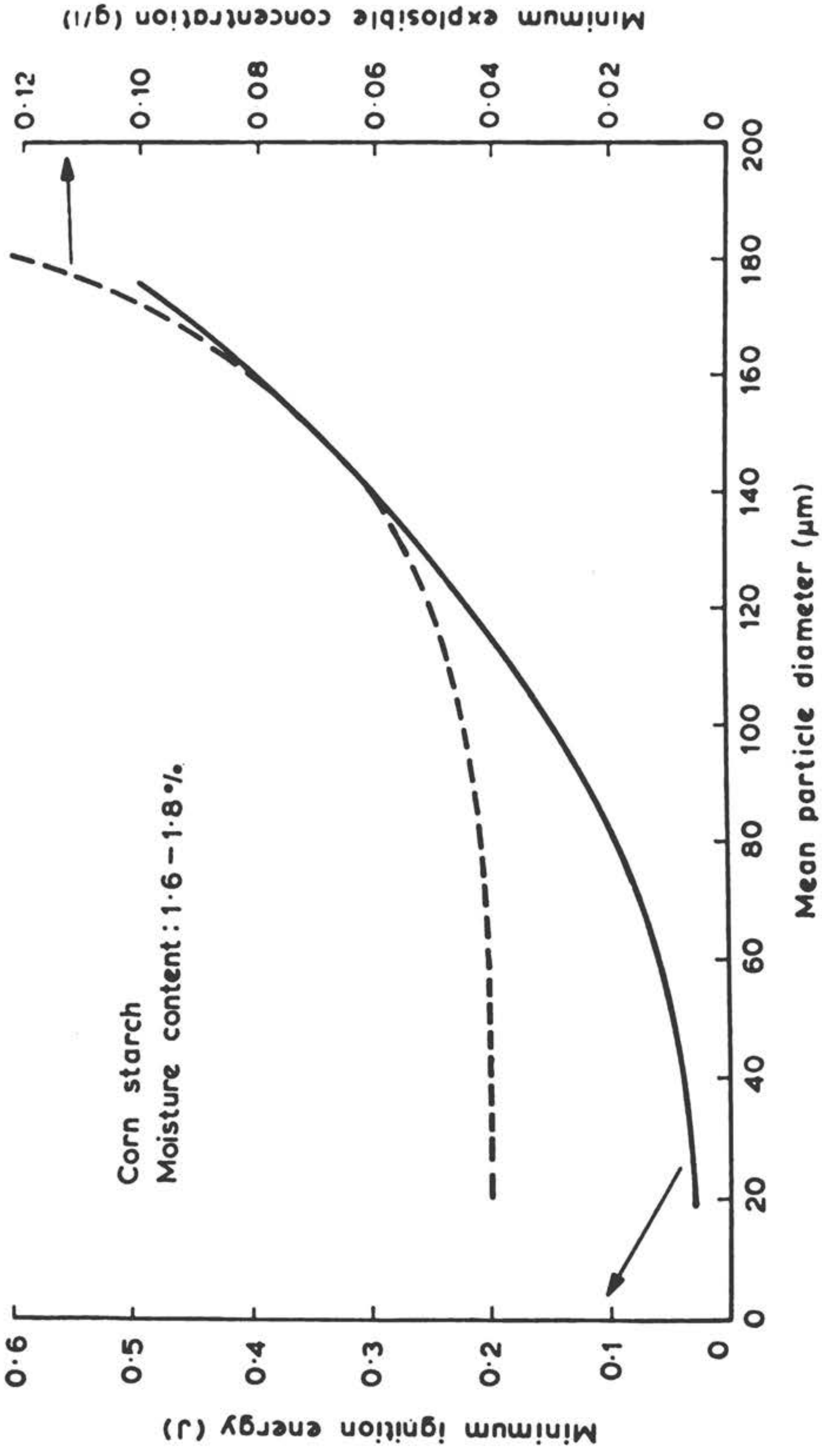


FIGURE 4 Schematic Energy Diagram for Combustion Reaction, Showing Energy vs. Band Length or Progress toward Reactions.

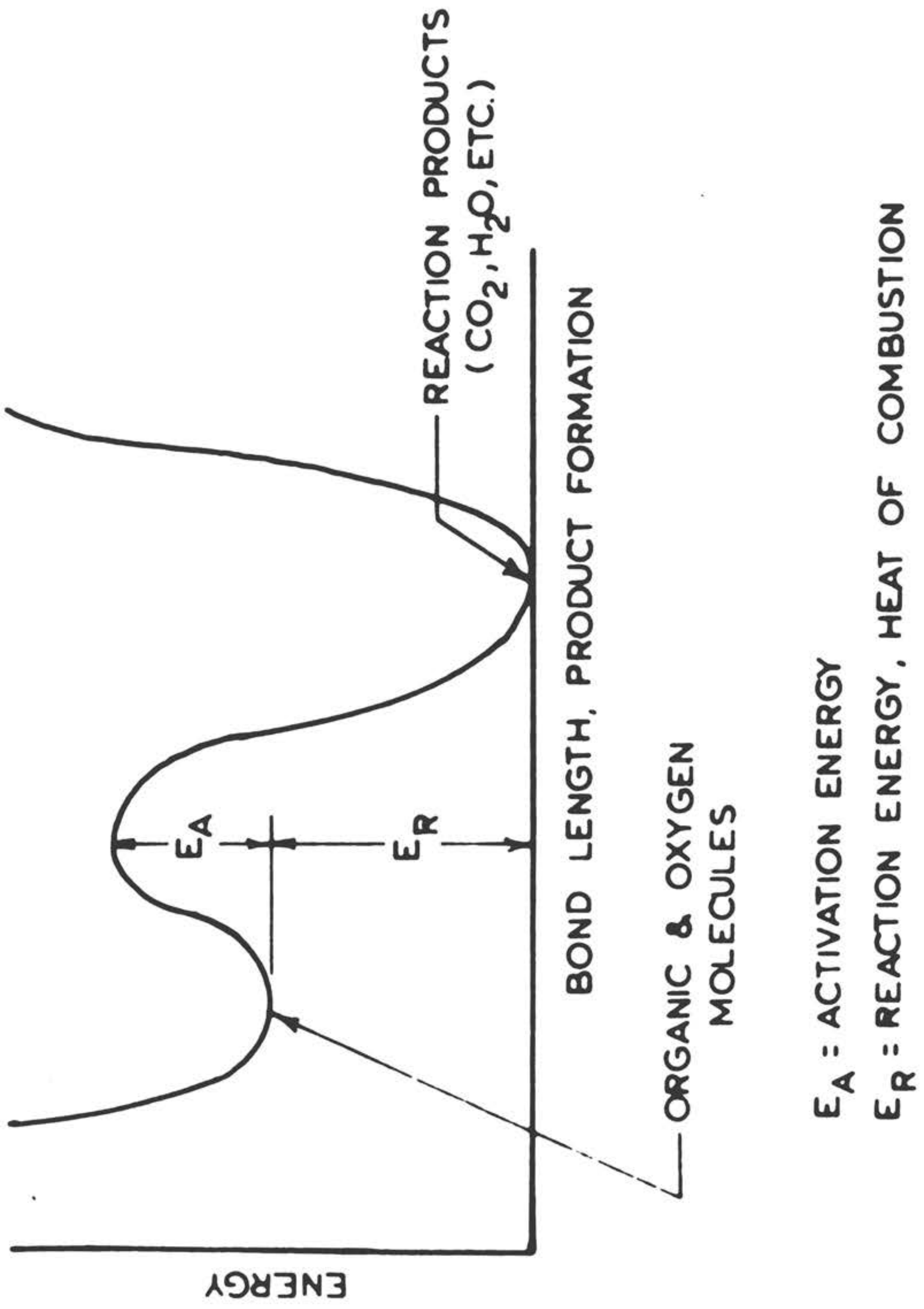


FIGURE 5 Minimum Ignition Energy (MIE) and Minimum Explosible Concentration (MEC) vs. Moisture Content for Cornstarch and Coal (Ref. 4).

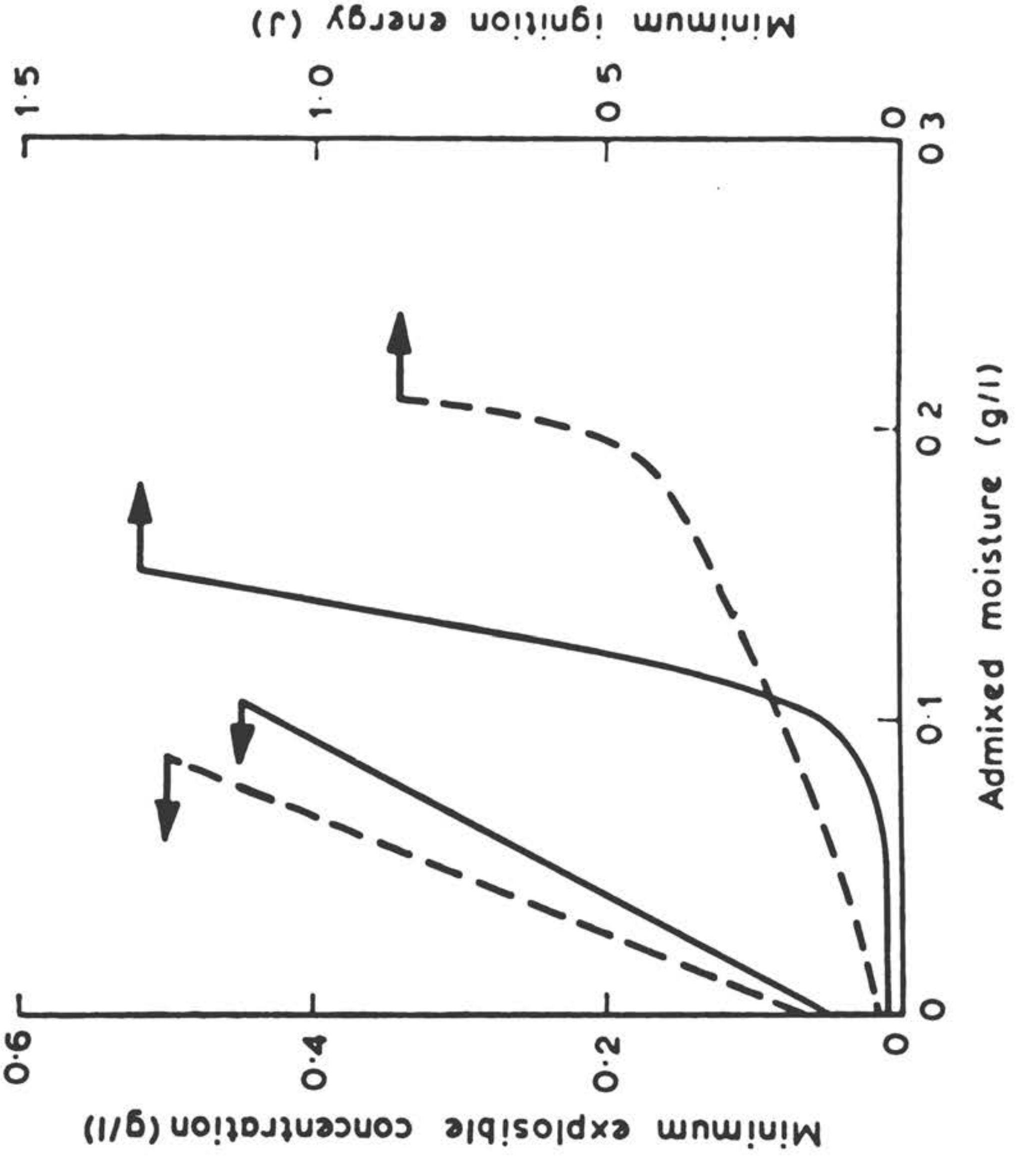


FIGURE 6 Minimum Ignition Energy (MIE) vs. Ambient Temperature for Various Coals (Ref. 2).

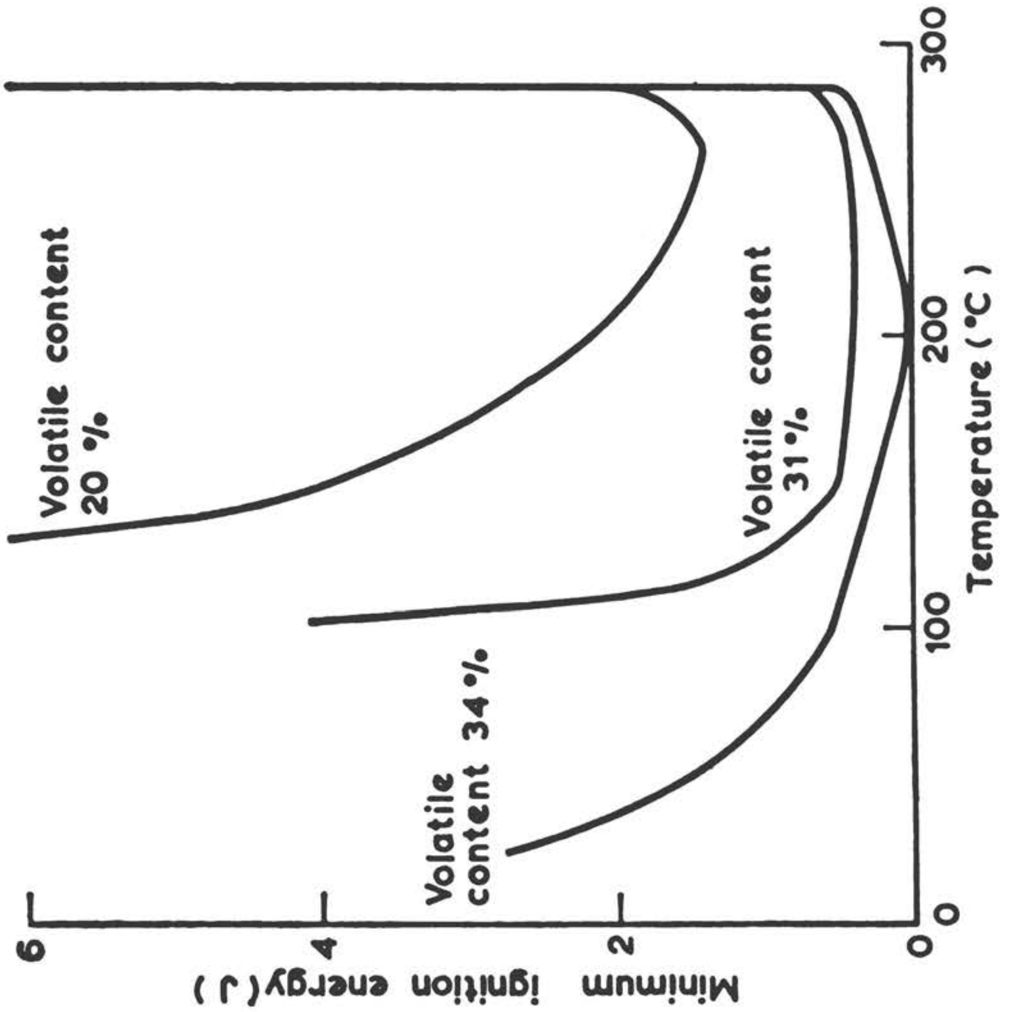
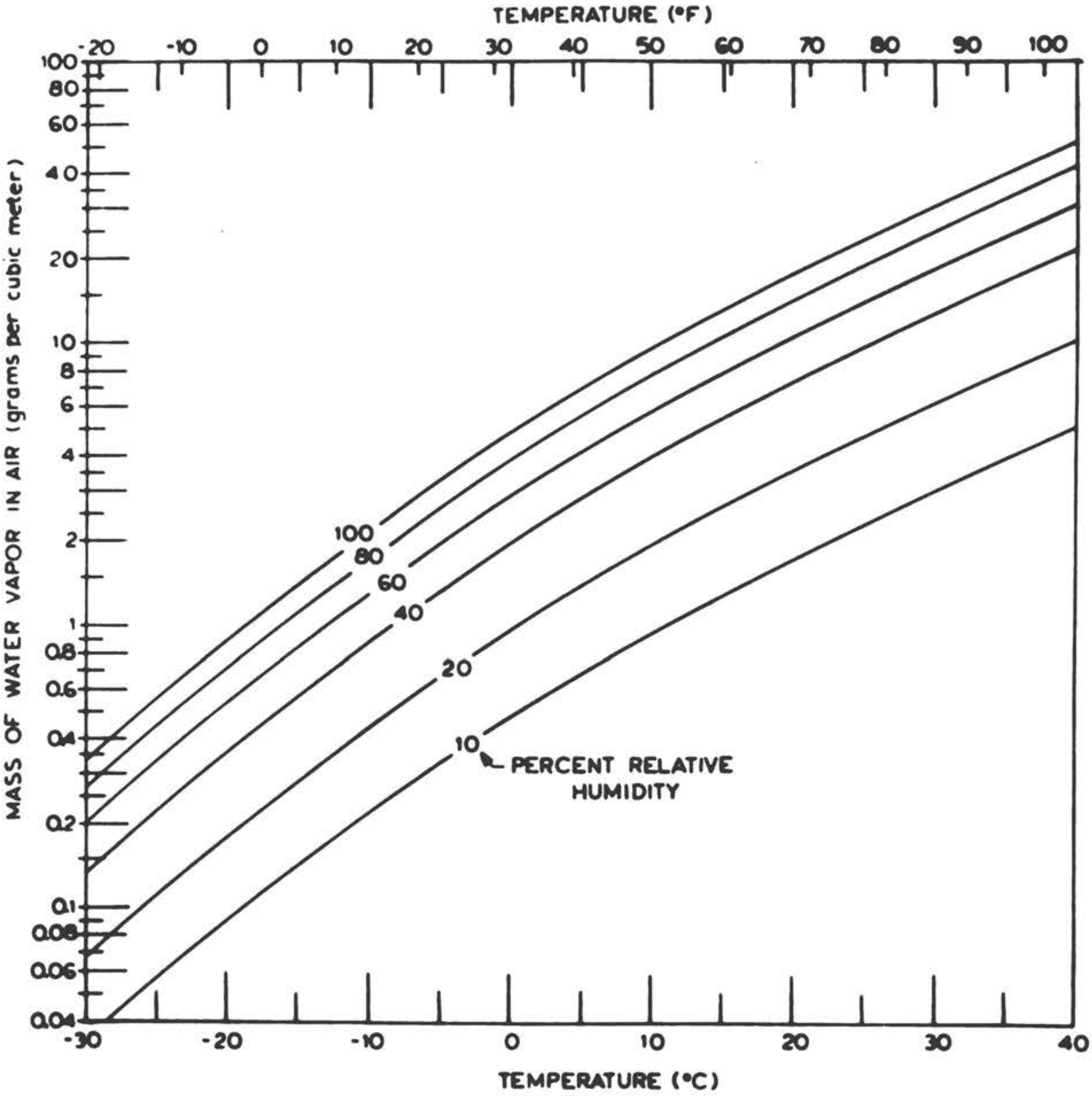


FIGURE 7 Mass of Water Vapor in Air vs. Temperature and Relative Humidity (basic data from Ref. 8).



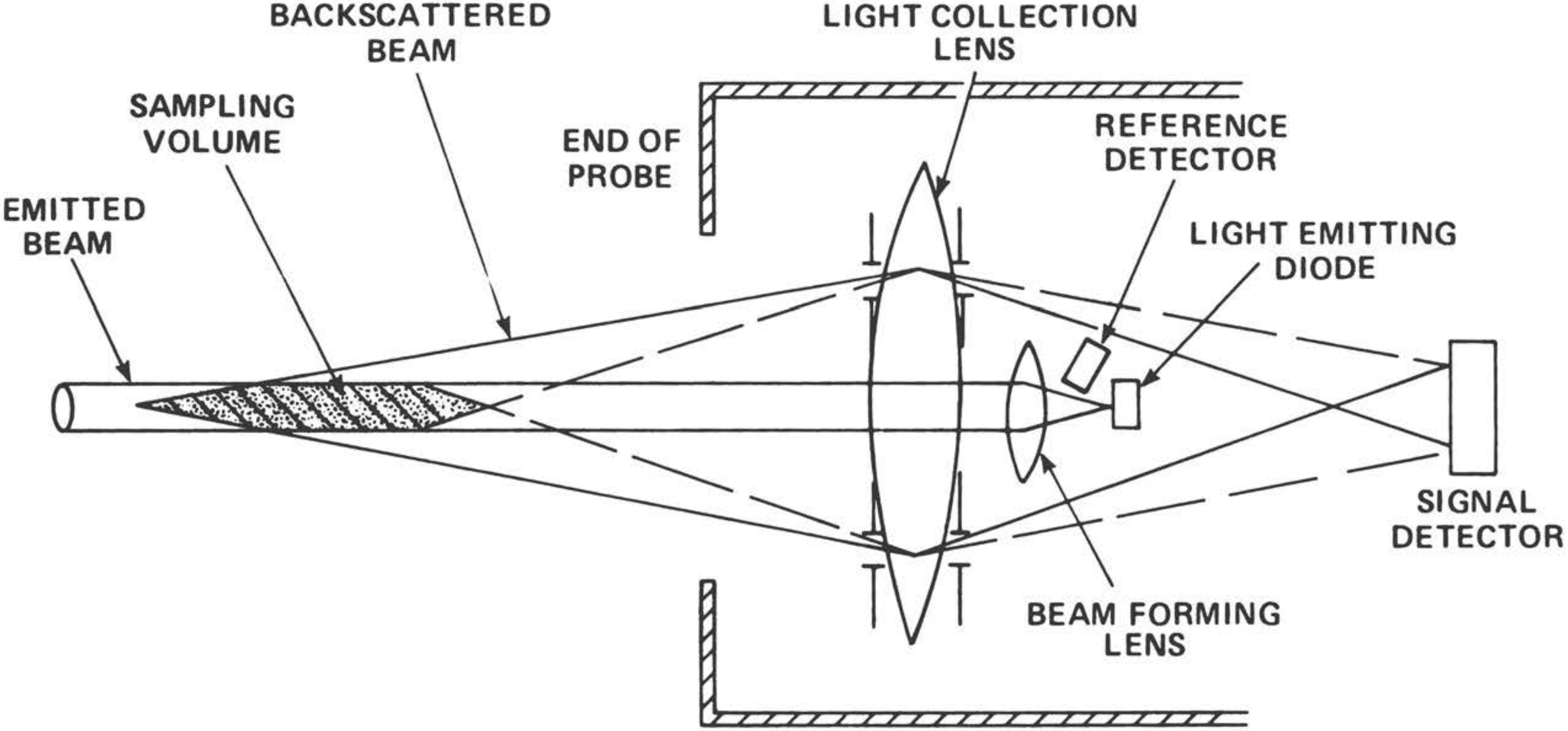


FIGURE 8 Schematic Optics Diagram for Dust Concentration Monitor.

FIGURE 9 Optics Assembly for Dust Concentration Monitor.

FIGURE 10 Schematic Diagram of a Terminal Elevator, Showing Circled "Critical Locations" where Highest Dust Concentrations Occur (Ref. 10).

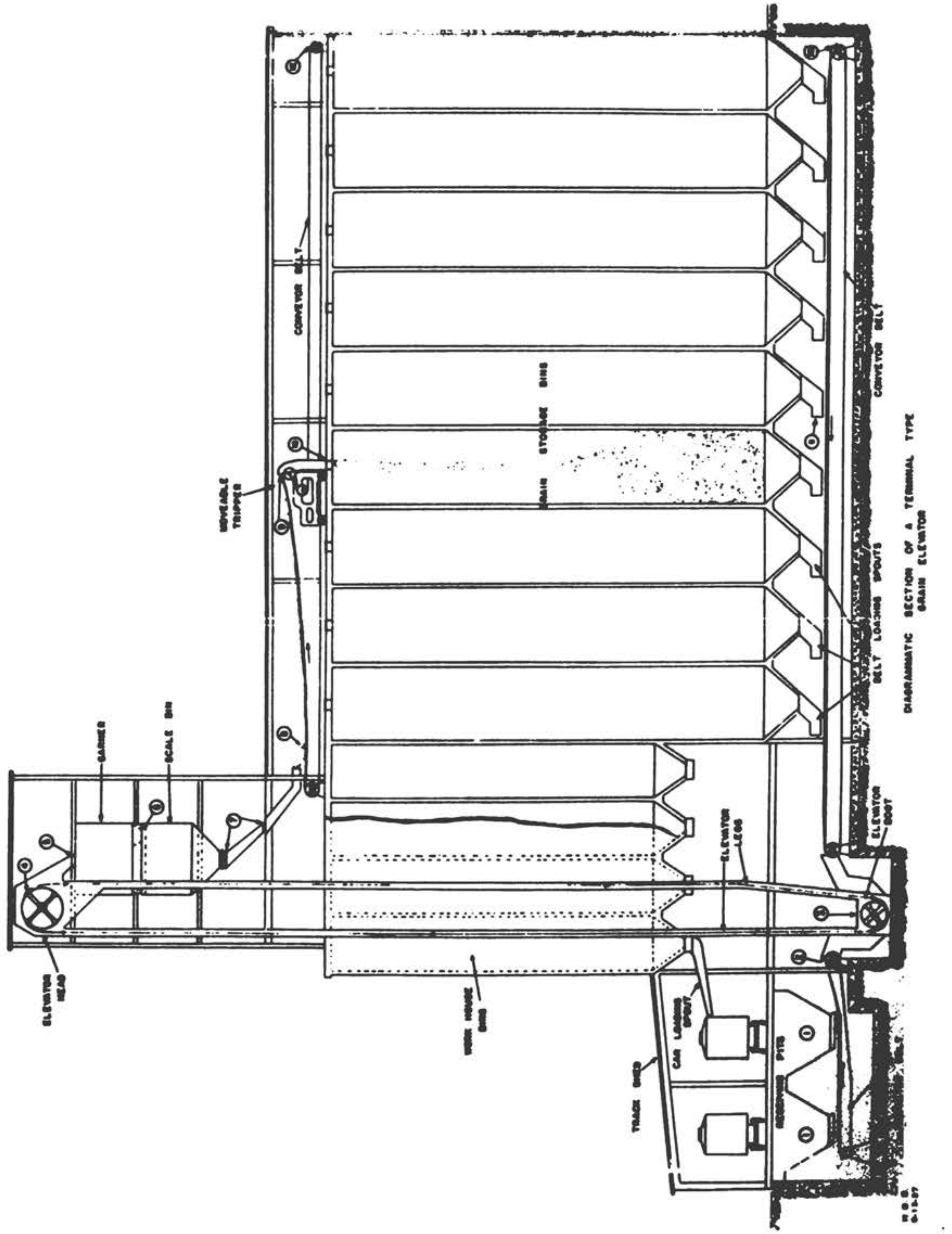
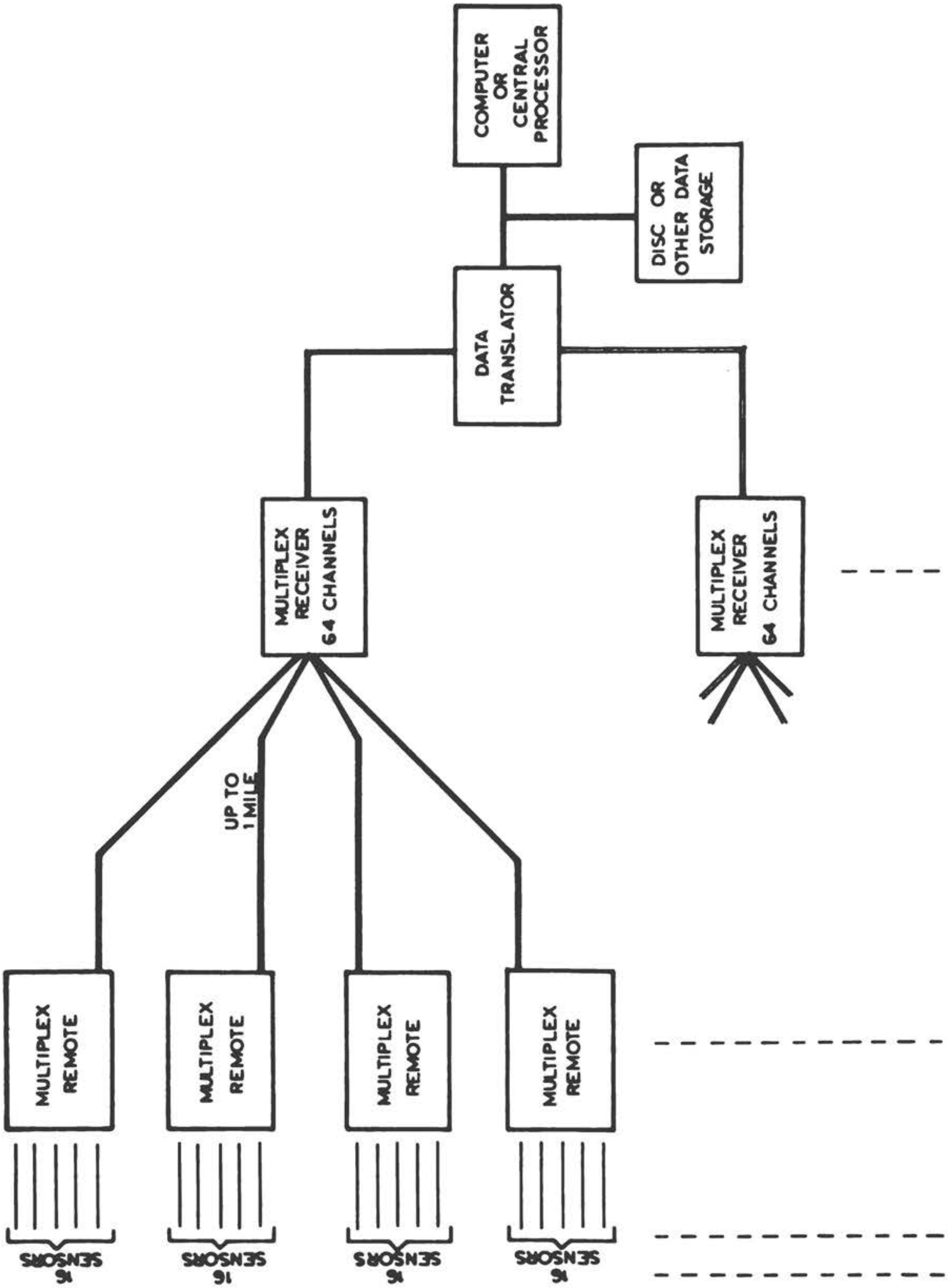


FIGURE 11 Schematic Diagram of Centralized Early-Warning System. Signals are transmitted from as many sensors as desired, via multiplex units, to central processor. Outputs (not shown) from central processor automatically activate alarms and preventive actions in equipment.



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MR. J. P. GILLIS JULY 12, 1978

EXPLOSION CONTROL

IN ORDER TO ADDRESS THE SUBJECT OF EXPLOSION CONTROL IT IS NECESSARY FIRST TO REVIEW THE NATURE OF DUST EXPLOSIONS AND THE PARAMETERS WHICH AFFECT THEM. ORGANIC SOLIDS WILL BURN RAPIDLY WHEN SUSPENDED IN AIR IN THE PROPER CONCENTRATION IN DUST FORM AND EXPOSED TO AN IGNITION SOURCE. THIS COMBUSTION PROCESS IS CHARACTERIZED BY THE EMANATION OF LIGHT AND HEAT. IF THE COMBUSTION OCCURS IN A CONFINED VOLUME IT WILL CREATE A PRESSURE RISE WITHIN THAT VOLUME. IF THE PRESSURE DEVELOPED EXCEEDS THE DESIGN STRENGTH OF THE CONFINING STRUCTURE, THEN THE STRUCTURE WILL RUPTURE. IN THIS CONTEXT, THEREFORE, EXPLOSION CONTROL MAY BE DEFINED AS A METHOD OR COMBINATION OF METHODS WHICH WILL ELIMINATE OR DRASTICALLY REDUCE THE POSSIBILITY OF VESSEL RUPTURE AS A RESULT OF EXCESSIVE INTERNAL PRESSURE.

WHEN A FLAMMABLE DUST CLOUD IS IGNITED IN A RUGGED LABORATORY VESSEL THE COMBUSTION CONTINUES UNTIL EITHER THE COMBUSTIBLE MATERIAL AND/OR THE OXIDIZING AGENT IS CONSUMED. PRESSURE DEVELOPMENT IS QUITE GRADUAL FOR A SHORT TIME INTERVAL AFTER IGNITION, BUT IT THEN ACCELERATES RAPIDLY AS GREATER QUANTITIES OF FUEL BECOME INVOLVED IN THE COMBUSTION PROCESS. THE MAXIMUM PRESSURE WHICH CAN BE DEVELOPED AND THE RATE AT WHICH THE PRESSURE IS DEVELOPED ARE DEPENDENT UPON INHERENT CHARACTERISTICS OF THE DUST ITSELF AS WELL AS THE PHYSICAL ENVIRONMENT IN WHICH THE COMBUSTION OCCURS. THE PARAMETERS WHICH EXHIBIT THE MOST AFFECT ON THE COMBUSTION PROCESS ARE DUST CONCENTRATION, PARTICLE SIZE AND GEOMETRY, MOISTURE CONTENT AND CONFINING VOLUME GEOMETRY. A BRIEF DISCUSSION OF EACH FOLLOWS:

1. CONCENTRATION

EACH FLAMMABLE DUST HAS A RANGE OF CONCENTRATIONS WHICH WILL SUPPORT COMBUSTION. THE LOWEST CONCENTRATION THAT WILL SUPPORT COMBUSTION IS CALLED THE MINIMUM EXPLOSIVE CONCENTRATION

AND MAY BE DEFINED AS THAT CONCENTRATION OF DUST SUSPENDED IN AIR BELOW WHICH EVEN IN THE PRESENCE OF AN IGNITION SOURCE, NO FLAME PROPAGATION WILL OCCUR. THIS MINIMUM CONCENTRATION WILL VARY DEPENDING UPON THE TYPE OF DUST, BUT IN GENERAL, WILL BE IN THE VICINITY OF .05 OUNCES PER CUBIC FOOT. AS THE CONCENTRATION OF THE DUST CLOUD IS INCREASED ABOVE THE MINIMUM EXPLOSIVE CONCENTRATION, CONFINED COMBUSTION OF THE DUST CLOUDS PRODUCES EVER INCREASING PRESSURES AND RATES OF PRESSURE RISE UNTIL A STOICHIOMETRIC CONCENTRATION IS REACHED AT WHICH TIME THE CURVE BEGINS TO REVERSE ITSELF AND THE PRESSURE DEVELOPMENT AND RATE OF PRESSURE RISE DECREASE WITH INCREASING CONCENTRATION. THE STOICHIOMETRIC CONCENTRATION FOR MOST DUSTS IS BETWEEN 0.5 AND 1 OUNCE PER CUBIC FOOT. THE UPPER LIMIT FOR DUST IS NEBULOUS ILL-DEFINED AND IS REACHED WHEN THE DUST CLOUD BECOMES SO DENSE THAT IT IS ABLE TO ABSORB THE HEAT FROM THE IGNITION SOURCE AND STILL NOT REACH ITS IGNITION TEMPERATURE.

2. PARTICLE SIZE AND GEOMETRY

THE RATE AT WHICH A GIVEN CONCENTRATION OF DUST IN CLOUD FORM BURNS IS AFFECTED BY THE PARTICLE SIZE OF THE DUST INVOLVED IN THE COMBUSTION. AS THE PARTICLE SIZE DECREASES THE RATE OF BURNING INCREASES AND, THEREFORE, THE RATE AT WHICH PRESSURE DEVELOPS INCREASES. CONVERSELY, COURSE DUST BURNS MORE SLOWLY AND IT IS DIFFICULT, IF NOT IMPOSSIBLE, TO ACHIEVE FLAME PROPAGATION IN DUSTS WHICH ARE COARSER THAN 60 MESH. THE PHYSICAL SHAPE OF THE DUST PARTICLE ALSO HAS AN EFFECT ON THE BURNING RATE. IN GENERAL, AS THE SURFACE AREA TO VOLUME RATIO INCREASES, THE RATE OF BURNING INCREASES.

3. MOISTURE CONTENT

MOISTURE IN THE DUST PARTICLES OF A DUST CLOUD IN A CONFINED VESSEL NOT ONLY REDUCES THE RATE OF FLAME PROPAGATION, BUT ALSO REDUCES THE MAXIMUM PRESSURE DEVELOPED. AS THE MOISTURE CONTENT IS INCREASED THE RATE OF FLAME PROPAGATION DECREASE UNTIL A POINT IS REACHED WHERE THE MOISTURE CONTENT IS SO HIGH THAT IGNITION CANNOT BE ACHIEVED.

4. CONFINING VOLUME

THE TIME REQUIRED FOR COMBUSTION OF A SPECIFIC DUST CLOUD CONCENTRATION IN A CONFINED VOLUME TO GO TO COMPLETION IS A FUNCTION OF THE VOLUME IN WHICH THE COMBUSTION IS OCCURRING. THIS TIME TO COMPLETION VARIES APPROXIMATELY AS THE CUBE ROOT OF THE VESSEL VOLUME. THUS, COMBUSTION OF A DUST CLOUD IN A 64 CUBIC FOOT VESSEL WILL TAKE ABOUT TWICE AS LONG AS COMBUSTION OF AN IDENTICAL CONCENTRATION OF THE SAME DUST IN AN 8 CUBIC FOOT VESSEL. IT FOLLOWS THAT IF ONE IS TO ATTACH ANY SIGNIFICANCE TO LABORATORY DATA PERTAINING TO RATE OF PRESSURE RISE DUE TO COMBUSTION IN A CONFINED VESSEL, THE VOLUME OF THE VESSEL MUST BE SPECIFIED.

5. THE FREQUENCY OF GRAIN ELEVATOR EXPLOSIONS HAS INCREASED DRASTICALLY OVER THE PAST TWO YEARS. A PREREQUISITE TO REVERSE THIS TREND IS A THOROUGH KNOWLEDGE OF THE NATURE OF GRAIN DUST EXPLOSIONS. THE QUESTION LOGICALLY ARISES, HOW MUCH DO WE PRESENTLY KNOW ABOUT GRAIN DUST EXPLOSIONS? THE ANSWER WOULD APPEAR TO BE - JUST ABOUT EVERYTHING. OVER THE PAST SEVERAL DECADES GRAIN DUST EXPLOSIONS HAVE BEEN STUDIED IN GOVERNMENT, INDUSTRY AND UNIVERSITY LABORATORIES THROUGHOUT THE WORLD. THE AMOUNT OF INFORMATION GATHERED HAS BEEN TREMENDOUS. THE NEXT STEP SHOULD BE THE PRACTICAL APPLICATION OF THIS KNOWLEDGE SO THAT THE HAZARD POTENTIAL IN GRAIN ELEVATORS CAN BE REDUCED OR ELIMINATED.

6. THERE ARE FOUR COMMONLY ACCEPTED METHODS OF EXPLOSION CONTROL. THEY ARE INERTING, CONTAINMENT, EXPLOSION RELIEF AND EXPLOSION SUPPRESSION. A BRIEF DISCUSSION OF EACH METHOD FOLLOWS:

A. INERTING

THIS METHOD OF EXPLOSION CONTROL INVOLVES THE REPLACEMENT OF A PORTION OF THE OXYGEN IN THE AIR WITH AN INERT GAS SO THAT THE RESULTING ATMOSPHERE CONTAINS TOO LITTLE OXYGEN TO SUPPORT FLAME PROPAGATION. WHERE NITROGEN IS USED AS THE INERT GAS, THIS CAN BE ACCOMPLISHED BY REDUCING THE OXYGEN FRACTION IN THE AIR FROM 21% DOWN TO APPROXIMATELY 12% TO 14%. THE OXYGEN CONTENT SHOULD BE

CONTINUOUSLY MONITORED IN THE VOLUMES BEING PROTECTED AND ADDITIONAL INERTANT SHOULD BE AUTOMATICALLY INTRODUCED INTO THE VESSELS WHEN THE OXYGEN CONTENT BEGINS TO RISE. ON THE SURFACE IT WOULD SEEM EXTREMELY DIFFICULT TO ADAPT THIS METHOD OF PROTECTION TO A GRAIN ELEVATOR, BUT PERHAPS A SYSTEM COULD BE DESIGNED IN WHICH AN INERT ATMOSPHERE COULD BE RECIRCULATED THROUGH TWO OF THE MOST VULNERABLE PIECES OF EQUIPMENT, NAMELY THE BUCKET ELEVATORS AND THE BAG FILTERS.

B. CONTAINMENT

THIS METHOD INVOLVES THE DESIGN AND CONSTRUCTION OF EQUIPMENT OF SUFFICIENT STRENGTH TO WITHSTAND THE MAXIMUM PRESSURE THAT COULD BE DEVELOPED DUE TO COMBUSTION OF A DUST CLOUD WITHIN THE EQUIPMENT. ALL DUCT WORK LEADING TO OR FROM THE EQUIPMENT MUST BE OF THE SAME RUGGED DESIGN; FAST ACTING PRESSURE-OPERATED VALVES ARE USED TO PREVENT FLAME FROM PROPAGATING FROM ONE PIECE OF EQUIPMENT TO ANOTHER. CONSTRUCTION OF THIS TYPE IS RARELY SEEN IN THE UNITED STATES, AND IT IS NEVER USED IN GRAIN ELEVATOR DESIGN. HOWEVER, IN EUROPE THERE ARE MANUFACTURERS OF BAG FILTERS WHO DESIGN THEIR EQUIPMENT UTILIZING THE PRINCIPLE OF CONTAINMENT.

C. EXPLOSION RELIEF

THIS METHOD INVOLVES EQUIPPING THE VOLUME TO BE PROTECTED WITH A WEAKENED SECTION OR VENT WHICH IS DESIGNED TO RUPTURE AT A LOW PRESSURE AND PROVIDES AN ESCAPE PATH FOR THE EXPANDING GASES WITHIN THE VESSEL. RELIEF PANELS OR VENTS SHOULD HAVE A LOW MASS AND AN ADEQUATE VENT RATIO. THE VENT RATIO IS DEFINED AS THE NUMBER OF SQUARE FEET OF VENT AREA PER 100 CUBIC FEET OF PROTECTED VESSEL VOLUME. IN MANY GRAIN ELEVATOR SILOS THE LENGTH TO DIAMETER RATIO IS SO GREAT THAT EVEN UTILIZING THE ENTIRE SURFACE AREA AT THE TOP OF THE SILO WOULD RESULT IN AN INADEQUATE VENT RATIO. GENERALLY SPEAKING, EQUIPMENT SHOULD ALWAYS BE VENTED TO THE OUTSIDE ATMOSPHERE. IF A PIECE OF EQUIPMENT IS VENTED INTO A ROOM

OR BUILDING IN WHICH THERE IS AN ACCUMULATION OF DUST ON THE FLOOR AND OTHER HORIZONTAL SURFACES, THE COMBINATION OF THE PRESSURE WAVE CREATED IN THE ACT OF VENTING, COMBINED WITH THE EMANATION OF FLAME FROM THE VENTED EQUIPMENT, CAN PRODUCE A SECONDARY EXPLOSION IN THE ROOM OR BUILDING MORE DEVASTATING THAN THE INITIAL EXPLOSION. BUCKET ELEVATOR LEGS AND BAG FILTERS WHICH ARE EXTERNAL TO THE GRAIN ELEVATOR WORK HOUSE CAN BE ADEQUATELY PROTECTED BY EXPLOSION RELIEF VENTING. HOWEVER, SINCE VENTING DOES NOT ARREST THE COMBUSTION PROCESS, SOME MEANS MUST BE TAKEN TO INSURE THAT FLAME DOES NOT PROPAGATE OUT OF THESE PIECES OF EQUIPMENT INTO OTHER AREAS.

D. EXPLOSION SUPPRESSION

THIS METHOD OF PROTECTION INVOLVES THE DETECTION OF AN EXPLOSION IN ITS INCIPIENT STAGE AND THE RAPID DELIVERY OF A SUPPRESSANT TO ARREST THE COMBUSTION PROCESS BEFORE DESTRUCTIVE PRESSURES ARE DEVELOPED. IN FLAMMABLE DUST APPLICATIONS THE NORMAL MODE OF DETECTION IS WITH PRESSURE DETECTORS WHICH CAN BE SET AS LOW AS 0.5 PSIG. DETECTION AND SUPPRESSION ARE ACCOMPLISHED IN A FRACTION OF A SECOND. PROTECTION FOR BUCKET ELEVATORS CONSISTS OF PRESSURE DETECTORS AND HIGH RATE DISCHARGE EXTINGUISHERS STRATEGICALLY LOCATED IN THE BOOT, LEG AND HEAD OF THE DUST ELEVATOR. THESE SYSTEMS ARE DESIGNED NOT ONLY TO SUPPRESS COMBUSTION IN THE ELEVATOR LEGS, BUT TO PREVENT FLAME FROM PROPAGATING OUT OF THE LEG INTO OTHER AREAS. THIS SAME TYPE OF SYSTEM IS ALSO PROVEN TO BE EFFECTIVE IN SUPPRESSING COMBUSTION IN THE HOPPERS OF BAG FILTERS.

SOMETHING MUST BE DONE TO REDUCE THE FREQUENCY OF GRAIN ELEVATOR EXPLOSIONS. THE IMPLEMENTATION OF ONE OR MORE OF THESE EXPLOSION CONTROL METHODS DESCRIBED ABOVE SHOULD REPRESENT AN IMPORTANT STEP IN THE ACHIEVEMENT OF THAT GOAL.

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ABSTRACT

EXPLOSIONS CAUSED BY TRAMP IRON REDUCED BY APPROVED MAGNETIC SEPARATOR INSTALLATIONS

by
Robert F. Merwin, Chairman
Eriez Magnetics
Erie, Pa., U. S. A.

While present U. S. codes are silent on mandating use of magnetic protection in grain storage and transfer elevators, an historic review of statistics in the textile and milling industries shows approved magnetic separation installations have dramatically reduced fires and explosions caused by tramp iron.

The paper advocates magnets be installed ahead of bucket elevators on the material entry side of grain elevators and recommends points of installation and specific types of magnetic separators required. Also included are tables showing sources of tramp iron (Table I), a partial list of explosive dusts tested by U. S. Bureau of Mines (Table II), and schematic plans for removing tramp iron on the material entry side of grain elevators (Table III).

* * *

This preprint for advanced study prepared for the International Symposium on Grain Elevator Explosions, Washington, D. C., July 11-12, 1978, conducted by --

National Materials Advisory Board
Commission on Sociotechnical Systems
National Research Council
National Academy of Sciences
on behalf of
U. S. Department of Agriculture

EXPLOSIONS CAUSED BY TRAMP IRON REDUCED BY APPROVED MAGNETIC SEPARATOR INSTALLATIONS

by

Robert F. Merwin, Chairman
Eriez Magnetics
Erie, Pa., U.S.A.

One of the major causes of fires and explosions in combustible dusts is tramp iron striking other metal or concrete. In addition, large pieces of loose iron can cause jams in legs of grain elevators. It is not unusual for magnetic separators to remove iron angles over 5 feet (1.524 meters) in length, and pieces of steel plate weighing 50 pounds (23 kilos). Quite obviously, foreign metal larger than the elevator bucket can cause a dangerous jam. When a jam occurs, unless there is an automatic cut-off, the head pulley keeps rotating and the belt carrying the buckets heats up from the head pulley friction and has been known to burst into flames.

Where does tramp iron come from? Table I lists several sources.

In the 1940's Factory Insurance Association of Hartford, Conn. records revealed over 7% of fire losses in the U.S. textile industry were due to tramp iron. Within 10 years FIA and Associated Factory Mutual engineers, working with a leading manufacturer of magnetic separation equipment, succeeded in a safety campaign that reduced tramp iron fire losses to less than 1%.

In the U.S. milling industry, processors are well aware of tramp iron as a major cause of fires and explosions, and commonly use magnetic separators ahead of processing equipment as called for in various codes of the National Fire Protection Association of Boston, Mass., and Mill Mutual Fire Prevention Bureau of Chicago, Illinois. For many years milling companies insured by Mill Mutual received a reduction in insurance premiums after a processor installed "approved" magnetic separators ahead of processing equipment. While safety codes of the National Fire Protection Association and insurance companies recommend or mandate the use of magnetic separators ahead of processing machinery, they have been silent on installation of magnetic separators to remove tramp iron entering grain storage and transfer elevators.

A consensus of both operating and insurance inspection personnel agree that with some minor changes in ranking of the order of importance, the major causes of ignition in grain elevators are --

1. Friction
2. Tramp Iron
3. Welding
4. Faulty Electrical Equipment
5. Static Electricity
6. Spontaneous Combustion
7. Careless Smokers

Table II contains a partial list of explosive dusts tested and listed by the U. S. Bureau of Mines. Many carbonaceous, metals, and plastics dusts (in addition to agricultural ones) are hazardous.

In all dust-explosive conditions it appears that removal of ferrous materials is highly desirable even though no processing is involved and grain is simply being transferred or moved into storage. It is clear that tramp iron can strike a spark not only when coming in contact with a bucket elevator, but also when striking a metal or concrete silo. The latter has been recognized by NFPA Code 61C - "Dust Explosion Prevention Feed Mills" - Sec. 410, which states --

> "4102. Spouts introducing dry material into tanks, bins, or garners should be designed and installed in such a manner that the stream will not strike the wall of the bin, to avoid the possibility of generating sparks with entrained tramp iron."

As in the textile industry, it would be desirable to reduce one of the major causes of explosions by mandating that receiving facilities for dry ingredients be equipped with an approved electro or permanent magnetic separator installation to remove tramp iron.

It is impractical and impossible for magnets to remove small ferrous contamination of 30 grams or less in the receiving facilities of grain elevators; however, large and medium sized spark-producing iron is being magnetically removed in many grain elevators with operating efficiencies as high as 99.5%.

Table III shows some schematic magnetic installations now being used effectively in elevators operated by safety-conscious companies.

Most commonly used grain elevator protective magnets on receiving belts are powerful electromagnets suspended over the conveyor. Magnets are often equipped with a self-cleaning belt and can remove tramp iron from high-speed, high-volume conveyors. It is desirable to specify magnets and the attendant rectification equipment that carry approval by Underwriters Laboratories, Canadian Standards Association or similar safety equipment testing bodies.

Medium and small capacity elevators have additional options in the installation of effective magnetic protection ahead of bucket elevators. These include --

(1) A permanent suspended magnet over a belt with a moderate burden depth.

(2) A permanent magnetic self-cleaning head pulley at the end of a belt conveyor.

(3) A magnetic grate in the lower portion of the receiving hopper. This device is comprised of banks of one-inch-diameter magnetic tubes staggered in such a manner that all materials come in contact with the 360° magnetic surface. Ferrous contamination is literally "combed" out of the grain. Grate magnets for tramp iron removal must be manually cleaned.

(4) Another alternative is powerful nonelectric plate magnets which can be installed as part of the bottom of gravity chutes leading to elevators. This common "workhorse" also requires manual removal of captured metal.

The magnetic hump, as shown at the lower left of Table III, is commonly used at the beginning of pneumatic conveying lines to meet NFPA Code No. 66, Sec. 641, which states --

> "Magnetic (or other protective equipment) shall be provided to prevent entrance of ferrous materials into the pneumatic system."

A number of different types of magnetic separators have been discussed here, but they all fit into two basic categories -- electro-powered and nonelectric (permanent) magnets. These in turn are divided into self-cleaning units or those requiring manual removal of tramp iron. Units are available in varying sizes and magnetic field strengths.

In virtually every installation the manner in which the material flow enters the magnetic field is of prime consideration to achieve effective separation. Moderate burden depths and speeds and an even flow are highly desirable. Where baffles can't be used to spread material flows, the best way to feed magnetic separators (and most bulk materials processing machinery) is with screw or vibratory feeders. The latter type is preferable as it spreads the material evenly and the flow rate is easily changed by remote controls.

Selection and application of magnetic equipment to solve all but the simplest removal problems should not be left to personnel with little magnetic separation experience. Experts in magnetic separation equipment can best be found within the ranks of experienced full line equipment manufacturers who will conduct surveys and make recommendations without cost. It is wise to specify electromagnets approved by Underwriters Laboratories to meet insurance inspection requirements.

Fortunately, magnetic protection is usually not a costly investment and can frequently be installed in existing lines with little or no revamping.

The Wall Street Journal states --

> "In the last two years (1976-77) there have been 26 major explosions in U. S. grain elevators. This rate of 13 a year is up from the annual rate of about eight explosions for the previous 15 years. One report shows that in a recent four-year period grain elevators and processing plants averaged about 2,500 fires a year, causing average property loss of more than $46 million a year."

There is historical proof that the widespread use of "approved" magnetic separators in processing industries has greatly reduced fires and explosions. In addition, removal of metal trash has saved bucket elevators, screens and other equipment from damage and quality of the product has been upgraded.

Magnetic separation technology and products are available to help eliminate one of the major causes of dust explosions in grain storage elevators and processing plants. It is encouraging to note the interest and activity among progressive elevator operators to eliminate a major source of explosions -- unwanted tramp iron.

TABLE I

SOURCES OF "TRAMP IRON" IN PROCESSING LINES

INCOMING MATERIALS

1. From fields, mines, pits -- from harvesting, digging, boring and blasting equipment.

2. Loose iron from railroad cars, trucks, ships, open conveying equipment.

3. Nails from crates, boxes, skids; steel slivers from cans and drums; strapping and tie buckles from bales.

4. Deliberate loading of bags, boxes and bales with iron or stones at source of supply to increase value of materials sold by weight.

IN-PLANT SOURCES

5. Steel parts and fastenings from processing equipment, in-plant conveyors, bucket elevators, hoppers, pipes, adaptors, etc.

6. From initial assembly or repair work, debris such as welding rod and splatter, bolts and nuts, tools, etc.

7. Accidental entry of iron from poor housekeeping and carelessness (from boiler plate to bottle caps).

8. Purposeful sabotage by throwing tools or scrap iron and steel into processing lines ahead of dies and other vulnerable equipment.

* * *

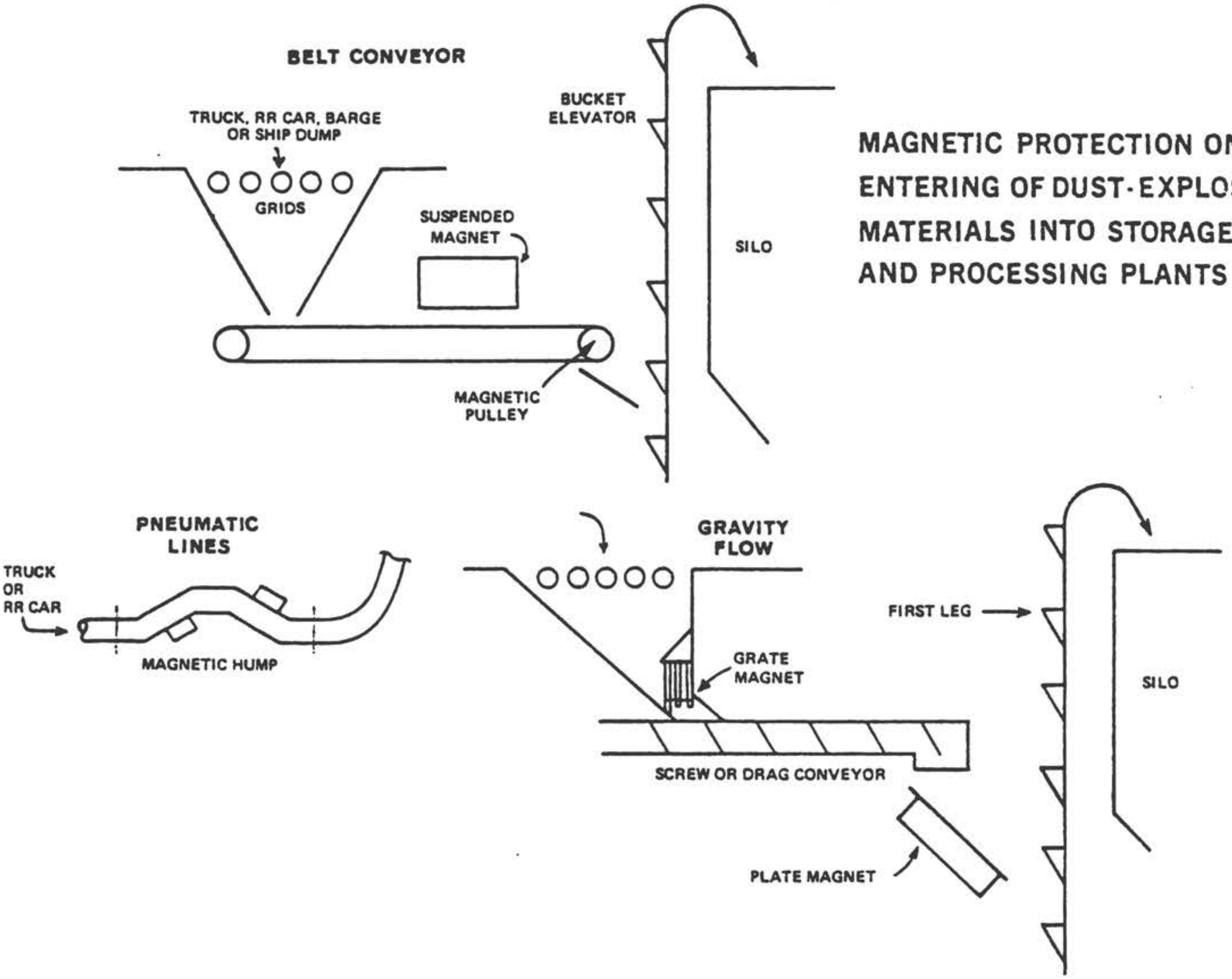
The table does not include small ferrous contamination such as rust scale or iron of abrasion coming from a variety of sources which must be removed from both liquid and dry foodstuffs, chemicals and pharmaceutical products, etc.

TABLE II

EXAMPLES OF EXPLOSIVE DUSTS

AGRICULTURAL	CARBONACEOUS	METALS	PLASTICS
WHEAT	COAL	ALUMINUM	ACETAL RESIN
WHEAT FLOUR	ASPHALT RESIN	IRON	ALLYL RESIN
CORN	CHARCOAL	MAGNESIUM	UREA
RICE	LIQUITE	SILICON	ETHYL CELLULOSE
SUGAR	PITCH, COAL TAR	THORIUM	PETROLEUM
COCOA		TITANIUM	RESIN
MIXED GRAIN		URANIUM	EPOXY RESIN
MALT		ZIRCONIUM	PHENOL FURFURAL
STARCH			PHENOLIC RESINS
NUTS			POLYCARBONATE RESINS
COTTON LINTERS			POLYETHYLENE RESIN
WOOD FLOUR			POLURETHANE RESIN AND FOAM
			RUBBER
			VINYL POLYMER RESIN
			POLYVINYL BUTYRAL

TABLE III


MAGNETIC PROTECTION ON ENTERING OF DUST-EXPLOSIVE MATERIALS INTO STORAGE AND PROCESSING PLANTS

May 24, 1978

GRAIN INDUSTRY CONVEYOR AND ELEVATOR BELTING STATIC ELECTRICITY CONSIDERATIONS

By: Dr. James I Nutter,
Research & Development Manager
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For: The PVC Belting Manufacturers Association[1]

It is helpful to take note of recent studies and evaluations being done to determine the scope of the static electricity problem in conveyor and elevator belts. It is also interesting to attempt to relate these practical studies with the more theoretical investigations concerning dust explosions and fires.

In recent work, the PVC Belting Manufacturers Association[1] presented their findings for spark discharge energy tests using samples of currently available conveyor belting.[2] The results showed that when conditions simulating the most unfavorable and improper operational conditions . . . an ungrounded system . . . are used, all belts in the study were capable of discharging spark discharge energies . . . perhaps large enough to ignite some combustible dusts. It was also demonstrated in these tests that there are considerable differences in residual electrical energy between belts with different surface resistances. Antistatic type conveyor and elevator belts with surface resistances in the 10^7 to 10^9 ohm range had lower spark discharge energy values and more residual electrical energy still stored on the belt than conductive type belts with surface resistances in the 10^3 to 10^5 ohm range.

In the work of Eckhoff[3], data is presented that show that the energy dissipated in the spark is only a small fraction of the total energy stored when certain series resistances are in the discharge circuit. This would seem to indicate that as series resistances similar to the surface resistances of antistatic PVC conveyor and elevator belting reach 10^6 to 10^9 ohms in the discharge circuit, the spark energy is only of the order of 5% to 10% of the initial stored energy. Similarly, Palmer[4] also indicates that there is evidence that the electrical circuit producing the spark can also affect the net spark energy or ignition energy. However, Palmer[5] also raised the question that high resistivity plastics used as structural materials such as in tanks may possibly increase the hazards of static electricity spark discharges. In this work, Palmer apparently is referring to unplasticized materials such as polyethylene and polyvinylchloride that are essentially electrical insulators in their pure state. Highly plasticized materials such as PVC coatings used in flexible belting normally have much more moderate resistivity levels.

For example, unplasticized PVC is in the 10^{14} ohms surface resistivity range, normal plasticized and flexible PVC is in the 10^9 ohm range and antistatic plasticized PVC . . . such as is used in flexible coatings for conveyor and elevator belting . . . is in the 10^7 ohm surface resistivity range.

In general, minimizing the generation and storage of static electricity in conveyor and elevator belts is useful, but it cannot be relied upon for complete protection. As with other electrical energy problems, the main protection against ignitions from static electricity is essentially proper electrical grounding of all components in the installation and the maintenance of electrical continuity at all times during operation and for the lifetime of the plant.

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International Symposium on Grain Elevator Explosions

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"Settling the Dust in Australia"

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Australia is a significant producer of most grains and is one of the world's major exporters of wheat.

Most of the grain is produced in the five mainland States with New South Wales and Western Australia being the largest producers. Because of its smaller population and isolation from the other States, Western Australia exports overseas a larger proportion of its total crop than do the other States.

Each State has a bulk grain handling authority. These authorities are licenced receivers for the Australian Wheat Board and most receive other grains on behalf of State grain marketing bodies. A large part of the grain produced in Australia for marketing is delivered to the bulk grain handling authority in the producing State.

The bulk grain handling authorities have established a system of receival silos (elevators) in the main producing areas. Most of the grain produced is received into these country silos and transported to either port terminals or various home consumption outlets. Some grain is, however, delivered direct to port terminals by farmers.

The number of port terminals and country silos in each of the States are as follows:-

State	Port Terminals	Country Silos
South Victoria	7	110
Victoria	2	230
Tasmania	2	-
New South Wales	2	271
Queensland	2	74
Western Australia	6	245
	21	930

The bulk grain handling authorities in Australia have an extremely good safety record as far as grain dust explosions are concerned. Since the bulk handling of grain began, almost sixty years ago, there has been only one known case of an explosion in a bulk grain storage facility. That explosion was not attributable to a grain handling operation and fortunately was of a relatively minor nature with no permanent, serious personal injury resulting.

This record has been achieved through the consistent observance of good practices, with careful attention to hygiene and other safety aspects in all operational and maintenance activities. The various authorities have shown a continuing awareness of the need to practice good housekeeping at all times and to effect improvements where these are reasonably possible, whether by way of changed operational practices, or such things as better dust extraction facilities and silo design. There is a general prohibition on potentially dangerous activities such as welding or metal cutting, but if there is an unavoidable need for such things to be done, they are carried out under the most stringent safety conditions.

Each of the authorities has appointed safety officers whose duties involve concentration on elimination of accidents, including dust explosions. Safety Committees have been set up at larger installations and employee participation in these committees has helped to increase safety consciousness and eliminate sources of possible danger.

A great deal of co-operation exists between the various authorities with considerable interchange of information. Additionally, senior officers of each authority have been co-operating in the preparation of an operations safety manual which is designed as a guide for operators at ports and country silos. It covers a range of safety factors, including the inherent dangers of dust in the operation of silos.

Because of the writer's background, the Western Australian scenario constitutes the main basis of this paper, although each State shares a common philosophy and has adopted similar practices, procedures and equipment.

Western Australia is the largest State in Australia stretching about 2,400 kilometres in a north-south direction and about 1,600 kilometres in a west-east direction. A little more than one third of the State lies within the tropics, while the remainder extends southward to the temperate zone. The grain growing area is mostly in the southern part of the State where the climate is of the typical Mediterranean type.

Perth has more sunshine and a greater number of clear days in the year than any other State capital city. It also has the wettest winter, the driest summer and is the windiest of the capital cities.

Temperatures, average rainfall and relative humidity readings for the port terminal areas in Western Australia are set out below. This information has been included so that the ideas about these factors as influences in the grain dust problem can be tested against the relevant data.

Geraldton	Jan.	Mar.	May	July	Sept.	Nov.	Year
Temperature:							
Mean Max., °C	31.6	30.6	24.0	19.4	21.6	27.1	25.7
Mean Min., °C	18.7	17.5	12.6	9.2	8.8	13.7	13.5
Highest Max., °C	47.7	44.3	36.6	28.8	35.8	42.7	47.7
Lowest Min., °C	8.9	8.3	2.2	0.8	1.8	3.8	0.5
Perth							
Temperature:							
Mean Max., °C	29.5	27.7	20.6	17.2	19.3	24.5	23.1
Mean Min., °C	17.5	16.4	11.4	8.8	10.1	13.7	13.0
Highest Max., °C	43.7	41.3	32.4	26.3	32.7	40.3	44.6
Lowest Min., °C	9.2	7.7	1.3	1.2	2.6	5.6	1.2
Bunbury							
Temperature:							
Mean Max., °C	27.5	25.8	19.8	16.8	18.2	23.0	21.8
Mean Min., °C	14.8	14.1	10.2	8.2	9.2	12.1	11.4
Highest Max., °C	41.2	38.3	28.7	22.3	28.8	37.7	41.2
Lowest Min., °C	5.6	4.1	0.1	-2.2	-1.1	4.0	-2.2
Albany							
Temperature:							
Mean Max., °C	25.8	24.2	18.5	15.7	16.7	21.1	20.2
Mean Min., °C	13.3	12.9	9.5	7.4	7.4	10.4	10.2
Highest Max., °C	45.6	40.8	35.2	23.1	30.6	41.1	45.6
Lowest Min., °C	5.7	3.7	1.7	0.1	1.1	4.8	0.1

Esperance	Jan.	Mar.	May	July	Sept.	Nov.	Year
Temperature:							
Mean Max., °C	26.0	24.9	20.4	17.4	18.8	22.0	21.6
Mean Min., °C	15.2	14.8	10.3	7.8	8.8	12.0	11.5
Highest Max., °C	47.2	43.6	33.1	26.0	35.6	42.2	47.2
Lowest Min., °C	4.9	3.9	1.7	-0.6	1.3	3.3	0.6

Rainfall and Humidity

	Height above mean sea-level	Average Rainfall		Relative Humidity	
		May to October	November to April	May to October	November to April
	metres	mm	mm	%	%
Geraldton	4	407	61	67	62
Perth	19	768	122	69	55
Bunbury	5	761	127	77	70
Albany	13	730	225	76	73
Esperance		Information not available			

SOURCE: Western Australian Year Book 1977.

The abiding concern of the Australian bulk grain handling authorities is to ensure the maximum of cleanliness. For instance, the Grain Elevators Board of Victoria recently advised the writer of this paper, "Our efforts have been concentrated on regular and thorough cleaning of all installations - particularly those areas where dust settles and could later be dislodged to form a dense localised cloud. It is perhaps worth noting that all installations are washed down every year, both for insect control purposes and to remove accumulated dust, etc. We believe that this practice contributes very significantly to prevention of a build-up of dust."

At the same time the Grain Elevators Board of New South Wales also stated, "Strict requirements are enforced for continual removal of surface dust from storages".

Their reasoning, and that of all Australian bulk grain handling authorities is that without dust, there is no material to explode.

Extensive dust control systems are installed in all seaboard terminals. Whilst strict standards of cleanliness are required in country silos, there are few instances where these are equipped with extensive dust extraction equipment. Both New South Wales and Western Australia are exceptions. In the former State, a number of major inland terminals have had dust collection systems installed, each at a total cost of $A500,000. In some States portable vacuum cleaners are also used to supplement the fixed installations.

One of the fundamental features of the grain conveying system within most Australian grain terminals is that the machinery cannot be started until the dust extraction system is operating. Also, dust systems are so designed that they continue to operate for thirty minutes after the conveying machinery has stopped. This makes sure that dust is cleared from the duct work and dislodged from the filter bags. Another fundamental feature is that dust, once extracted, is not returned to the grain stream. It is collected in dust houses and taken from the terminal area for disposal.

Basic Design of Dust Collection Systems

In New South Wales the major installations are provided with filter bag dust collection systems. All dust filters are grounded to prevent the build-up of static electricity.

Basically, all systems in Western Australia are designed as balanced systems using the static pressure balance method enabling the required volumes of air to be drawn from each branch duct and hood without the need for blast gates and butterfly valves to be fitted to the duct work to regulate the volumes being handled. The systems where blast gates and butterfly valves are installed are often potential sources of blockages. When blockages occur they are often accompanied by a reduction of conveying velocity plus dust fall-outs in the ductwork.

Sweep-up systems, which play an important role in the cleanliness of grain terminals, are usually connected to the main duct runs. As the operation of these is only intermittent, they are not taken into consideration with respect to the ultimate volume of air that will be used when calculating the size of the dust filter. However, care is necessary when they are connected to the main header ducts in order to ensure that an adequate volume of air is available at each individual sweep-up to induce the floor sweepings into the sweep-up shoe.

On long runs of sweep-up ducting, booster fans are installed and duties calculated to ensure a correct static pressure balance entering the main duct. The minimum and maximum volumes of air used in sweep-up ducts are 1100 CFM and 1500 CFM respectively - minimum air speed in ducts is 3,600 FPM and maximum 5,600 FPM. This variation in air velocity allows for static balancing of the ductwork system.

In the mechanical conveying system it is normal to exhaust all points where grain is turned or where a point of impact exists and other areas where dust emission can take place. These include feed-on shoes to belt conveyors, grain delivery hoods on conveyors (including top and bottom hoods) drive end hoods on tripper conveyors, elevator legs adjacent to and above the boots, evacuation of bins, bagging machines, and rail track hoppers.

The filtering of dust from the conveying air is a process requiring considerable care. In Western Australia, a fabric type filter of United States design, and made in Australia under licence, is used. In two Western Australian grain terminals, Albany and Geraldton, Amerjet type filters (American AAF design) have been installed. It has been found necessary with this type of filter to instal orifice plates in the top inlets of the filter bags to effect satisfactory results. Most dust extraction systems incorporate a pre-cleaning unit which, in fact, is a centrifugal separator. The purpose of this is to reduce abrasion of the filter media by the heavier particles.

The filtration rate through the fabric cleaning elements is also very carefully considered, as too high a rate promotes clogging of the pores of the media and makes the system upstream of the filter less efficient. Most engineers now provide that the main exhaust fan is located on the side of the filter where it makes contact with the cleaned air. This ensures that the fan operates more efficiently and that wear is reduced to a minimum.

Dust collected in the hoppers of the dust filters and the heavy material collected from the pre-cleaners are delivered to a dust bin by either of the two following methods, the choice of which depends on the layout of the plant:-

1. Screw or drag chain conveyor.
2. Pneumatic conveying system (either positive or negative).

The dust holding bins are usually made to suit the volume requirements with respect to unloading and are generally circular in shape, with specially designed hoppers to assist in the free delivery of dust and preventing as far as possible bridging of the material in the bin. Where pneumatic conveying of material to the bin is used, it is necessary to mount a filter-type bin vent to the top of the bin to evacuate the conveying air.

It is relevant to note that trucks collecting dust must always stop their engines and they are not permitted to start them until the dust in suspension has subsided. In the newer dust houses the floors have been sloped so that trucks can roll out of the facility without having to start their engine.

Air volumes for the various systems are generally in line with the following but are subject to the grain's rate of flow, length of fall (say from an elevator head or grain distributor), angle of feeding spout, and of fall on to feed-on shoes.

HOOD TYPES	BELT WIDTH			
	36" 400 tph	42" 800 tph	48" 1000 tph	54" 1250 tph
Feed Shoes	1000 CFM	1200 CFM	1400 CFM	1600 CFM
Dust Hoods	600 CFM	800 CFM	1000 CFM	1200 CFM
Under Belt Hoods	400 CFM	450 CFM	500 CFM	550 CFM
End of Belt Hoods	Top 500 CFM Bottom 400 CFM	Top 500 CFM Bottom 450 CFM	Top 500 CFM Bottom 500 CFM	Top 500 CFM Bottom 550 CFM
Elevator Boots	1000 CFM	1200 CFM	1400 CFM	1600 CFM
Bin Exhaust	600 CFM	1000 CFM	1200 CFM	1500 CFM

When a dust collection system is being installed, it is considered satisfactory only if it meets with the following:-

(a) All collection points are exhausting at least the minimum volumes of air specified and, that the actual volume does not exceed by 15% of nominated volume. Sweep-up ducts are to pass a maximum volume of 1500 CFM.

(b) No dust emission is evident from the fan stack after passing the dust filter, when the plant is operating at full capacity in any, or all, dust systems.

Kwinana Grain Terminal

The above remarks apply to dust systems generally in Western Australia but there is now a very special terminal in that part of the world and a paper from Australia would be incomplete without some information concerning what is believed to be the largest grain shipping terminal in the world - the Kwinana Grain Terminal.

This terminal loaded its first ship on June 29th, 1977, so it is possibly a little premature to talk about its safety record. However, it is relevant for the purposes of this paper to outline some of the features of the dust control system which was installed at a total cost in excess of $A4·3 million. Many of these features represent the culmination of years of experience in dealing with various dust and operational problems.

The main aim of the dust control system as designed for Kwinana was not to select the dust from the grain parcel, but to eliminate or regulate its escape to the surrounding atmosphere.

The feed-on shoe is an accepted and efficient item of equipment, for feeding granular types of material on to belt conveyors, but in itself requires additional aids to prevent dust emission to the atmosphere. The aids chosen for the Kwinana Grain Terminal are rubber air baffles which restrict the usually large openings at each end of the shoe, to a degree, which causes a higher capture velocity and lower dust emission.

As an example, the average air volume used for a 48 inch (1,200 mm) wide belt conveyor feed-on shoe from a bin or similar feed is 1400 CFM (0·66 cubic metres/sec.). When grain is discharged from the end of a belt conveyor it is contained and guarded by a "discharge hood". At the point of grain impact, dust is generated and a method of preventing emission at the hood has been by means of an "under and over" combined hood assembly.

Again, baffling is required between the ends of the head pulley and the sides of the discharge hood, above the grain profile, and below the belt to restrict the "free air gap" and so increase the capture velocity, to prevent dust emission. With the Kwinana Grain Terminal the lower tapered conical section of the hood, has been fitted with tapered hoppers which, by means of a rubber belt scraper, helps to agitate and collect the dust which adheres to the belt after grain discharge. The average air volume used for a 48 inch (1,200 mm) wide belt discharge hood is 1,500 CFM (0·72 cubic metres/sec.).

Air movement through the ductwork systems (other than booster fans) is caused by non-overloading centrifugal type, direct coupled fans located on the "clean air" side of the dust filters and discharging directly to the atmosphere. In the Kwinana Grain Terminal, these fans are used mainly to overcome the resistance to air flow through the dust control ductwork, the skimmer pre-cleaners, and the fabric type filters with their connecting ductwork.

A horizontal design of centrifugal pre-cleaner is located in the air stream and on the inlet side of the dust filter to separate any grain, straw, or other heavy material and to prevent undue wear and possible damage to the bags and cages. The collected heavy materials fall into a hopper, to which is fitted a motorized rotary valve to discharge at the regulated rate by means of a pneumatic conveyor system to the storage or holding bins for eventual disposal.

The dust filters are of the fabric, baghouse type and separate the fine material from the conveying air before being discharged to the atmosphere by the main exhaust fan. The average rate of air flow through the fabric bags is 7·5 fpm (0·04M/sec.) which should result in a long life for the filter bags. The bags are cleaned by a regulated jet of compressed air, at pre-determined intervals, to maintain a low pressure drop with maintained and efficient air flow through the system.

As is the case with the heavy materials, dislodged dust from the bags fall down to the bottom of the filter hopper to which is fitted a screw type conveyor to move the collected material via a rotary valve to a second pneumatic conveyor system to feed direct to dust storage bins for disposal.

The transport of the dust is carried out by means of specially designed containers which fit domestically operated trailers for use within the confines of the terminal or specially fitted out tipping trucks.

<u>Summary of Dust Control System - Kwinana Grain Terminal</u>

1. <u>Systems</u>

Separate and integrated systems (This includes Pneumatic Conveyor and disposal evacuation systems)	45

2. <u>Air Volume</u>

Total air volume moved if all plant systems operative at one time	587, 310 CFM (20 tonnes approx.)

3. <u>Main Exhaust Fans</u> (Industrial Air Handling Ltd.)
(Richardson)
(Pitstock)

Total System exhaust fans	33
Total Connected horsepower	1680

4. <u>Dust Filters</u> (Ducon Mikropul)

Total number of individual filters	33
Total number of filter bags in use (bags 4½" dia. 8' 0" long and 10' 0" long)	8048
Average bag filter rate	7.74 FPM

5. Skimmer Pre-Cleaners (H.P. Gregory)

Size 20	5
Size 24	11
Size 27	10
Size 30	6
Size 33	1
Total	33

6. Rotary Valves (Ducon Mikropul)

Total number	66

7. Booster Fans (Pitstock)

Total number	129
Total connected horsepower	2117·5

8. Feed Shoes

Total number of Conveyor feed shoes with dust extraction connections	198

9. Conveyor Discharge Hoods

Total number of combined discharge and under belt hood connections	58
Total number of under belt hood connections	17
Total number of end of belt hood connections	27

10. Tripper

Total number of connections for tripper exhausting	502

11. Cleaning Machines

Total number of connections to grain cleaning and grading machines	68

12. Elevator Boots

Number of connections to each boot 1	
Total	10

13. Grain Distributors

Number of connections to each 1	
Total	10

14. Distribution and Garner Bins

Number of connections to each 1	
Total	12

15. Floor Sweep Hoods

Vertical up type	547
Vertical down type	58

16. Pneumatic Conveyor Branch Ducts

No. 1 and No. 2 Dust Houses	37

17. Ductwork

Diameter of ductwork ranges from 3" to 33"

Approximate number of duct clean out doors fitted to the ductwork is 2800

18. Dust Houses

The two new dust houses are located adjacent to and on the eastern side of silo groups 1 and 2

The overall dimensions of Dust House No. 1 are 245' 0" long 44' 0" wide x 80' 0" high, and No. 2 Dust House - 187' 0" long 44' 0" wide x 80' 0" high

Each dust house contains 3 dust holding bins with capacities as follows:-

No. 1 Dust House - 15,000 cft
No. 2 Dust House - 13,500 cft

A dust holding bin is located in the offshore transfer tower, with a capacity of 1400 cft

Each gantry loader has a holding bin of approximately 300 cft capacity

The filling time for each bin depends on the cleanliness of the grain being handled, rate of handling, number of exhaust points etc.

Designed Safety Features in Western Australian Port Terminals

All conveyor and elevator drive pulleys are rubber lagged. In the case of the conveyors, the lagging is vulcanized to the pulley and provided with Chevron grooving. The arc of contact of the belt to the conveyor pulley, the position of gravity take-up on most of the conveyors, and the method of drive ensures that no slippage will take place on start-up or during running. The conveyor drives are either from slip ring or squirrel cage motors through hydraulic couplings or, in the case of small conveyors, from squirrel cage motors through flexible couplings and gear boxes to the conveyor drive pulleys. These arrangements generally provide smooth acceleration to full belt speed.

Excessive friction leading to overheating of equipment is frequently cited as a contributing factor in grain dust explosions. The most prominent causes are slipping of conveyor belts on drive pulleys, seizure of idler pulley bearings, buckets dragging on elevator casings or overloading and choking of conveyor systems with grain. In most Australian grain terminals belt movement is monitored by a speed response switch connected to a pulley driven by the belt thus detecting any appreciable slippage of the main drive pulley. The tripping of a conveyor by a speed response switch means that, that conveyor cannot be run again until the fault is rectified. Electrical interlocking ensures that all preceding conveyors are stopped in such instances. Similarly, blocked chute and blocked elevator boot detectors are provided to prevent conditions which could initiate overloads and potential hazards. Also garner bin level switches provide warning signals (by hooter, light or indicator in the control room) for operators to adjust grain feeds before an overflow causes bogging and thus an overload and possible heating of motors. The operator in the main control room cannot override any of the safety features provided.

All conveyors, including the vertical bucket elevators are fitted with belt tension and pulleys which virtually eliminate the likelihood of belt slippage or bucket contact with the elevator casing. Where splicing of conveyor belts is necessary, vulcanizing is adopted instead of metal belt joiners as these can cause sparks through contact with the idlers. A belt running-off is another potential source of ignition and to obviate this possibility, belt run-off detectors are fitted. These consist of a pair of detector fingers each side of a conveyor belt and linked to a limit switch. Should the belt wander in excess of the distance pre-determined as an appropriate limit for safety, it will contact the fingers and set off the limit switch which stops the conveyor and preceding conveyors in that grain path. Belt run-off detectors can be installed at any place on a conveyor where trouble is likely to be experienced but the usual place is adjacent to the head or drive pulley.

Regular maintenance schedules are observed in order to protect terminals from overheating due to mechanical malfunctions. These schedules ensure that all equipment is inspected at least monthly and overhauled at regular intervals. In the main, maintenance is based on a preventative philosophy rather than a break-down philosophy; the latter being the norm in many other industries.

Specifications for construction of grain silos and terminals in Australia include provisions that they be built to comply with all statutory requirements for buildings, machinery, safety and electrical installation. Government safety requirements often change over the passage of time but all new installations are constructed in accordance with the latest codes. Also, when a particular facility is being maintained or repaired, the opportunity is then taken to up-date as far as possible any equipment which may have been affected by a change in the relevant code.

Throughout the various grain terminals, the entire electrical installation and components which includes such items as motors, switches, power outlets and light fittings comply with the requirements of SAA Wiring Rules, which are mandatory throughout Australia. The grain handling areas are classified as Class 2, Division 1 hazards which closely approximate the United States classification, Class 2, Division 1, Group G. The result is that all components are either totally enclosed, as in the case with motors, or in dust ignition-proof enclosures, as is the case with light fittings, switches and power outlets or in the pressurized switch rooms with filtered air inlets.

On gantry loaders the electrical equipment is also fitted with dust ignition-proof enclosures where necessary and weatherproofed where there is exposure to the weather.

The entire electrical installation including the metallic enclosures are effectively grounded in accordance with the SAA Wiring Rules. A lightning protection system is also provided in all cases.

Neither terminals nor country silos are, however, fitted with heat sensing devices to detect friction where slipping of belts occurs or over-heating of bearings in elevators and conveyors. As stated previously, staff are usually stationed in the operating areas and they are educated to watch for unusual circumstances and report them if and when they occur.

A feature of some overseas grain exporting countries is that drying and pelletizing are carried out in various port terminals. These activities are not usually undertaken in the majority of Australian terminals, nor is grain cleaned to anywhere near the extent to which it is cleaned in other parts of the world. It may surprise, but the maximum moisture limit at which grain is received is 12% and usually averages a lot less. In Western Australia, gas fired or other combustion appliances are not located in any of the installations.

Building enclosures and galleries in grain handling areas are invariably constructed of non-inflammable materials and designed for pressure relief, venting with light wall cladding panels which would blow out in the unlikely event of an explosion. Concrete head houses are never seen in Australia and terminals are usually designed so that they incorporate spacious layouts in the working areas to minimize the effects of an explosion if this should ever occur. Australian grain handling authorities are careful that this advantage is not lost by allowing the standard of housekeeping to deteriorate to the point where major dust accumulations are tolerated. All cells are capped in order to eliminate one source of dust spread. However, the cells, when being filled are exhausted so that the resultant negative pressure prevents "blow back", the situation where pressure within a cell being filled discharges air and dust into the working area. To create negative pressure in a cell more air must be extracted than the total of the grain and air that is entering. Exhausting of a cell can be accomplished by two methods:-

(a) Extraction duct fitted to the cell top, and
(b) Extraction duct fitted to the tripper.

Care should always be taken to ensure that a tripper fits snugly to the cell feed opening. In Western Australia the tight and thus dust emission free connection has been achieved at most terminals by adjustable and manually fitted connecting plates. Whilst at Kwinana brush contacts have achieved the same result.

Operating Practices

The Australian bulk grain handling authorities invariably ensure that some personnel are present throughout the relevant parts of the terminal when conveyors and machinery are running. This increases the likelihood that potentially dangerous occurences are detected and action taken before anything serious develops. Brooms are always on hand in each part of the terminal and every opportunity is taken when necessary to sweep dust and spilt grain to the sweep-up hoods. Vacuum cleaners are also very common and used frequently.

Visitors from other countries never cease to be impressed at the standard of cleanliness evident in Australian grain terminals.

Blowing down with compressed air is an integral part of the cleaning process. However, very strict rules are set down by the various bulk grain handling authorities governing when, how, and in what circumstances compressed air use is permitted.

The Grain Elevators Board of New South Wales has developed a most comprehensive set of instructions which reads as follows:-

"It is emphasized that compressed air should be used to blow down dust only when there is no other feasible means of removing the dust.

When it is necessary to use compressed air the following procedures and precautions should be taken on all occasions.

1. All machinery in the immediate vicinity of blow-down operations is to be shut down.

   This includes machinery in any area likely to be affected by a visible dust cloud.
2. All dust which is accessible is to be removed initially by hand or by vacuum appliance.
3. Regardless of whether it is in a blow-down area or not, each piece of machinery is to be checked periodically for possible ignition source such as:-

   (a) hot bearings, motor, gearboxes
   (b) faulty electrical wiring or missing plugs
   (c) any heat source
4. All tramp iron, loose bolts, stones, loose concrete or any loose spark producing material is to be removed by hand from the area.
5. Where an air hose is to be lowered into a bin or other difficult access area, the wand and fittings are to be of brass. Steel or aluminium are not to be used.
6. Contractors or non G.E.B. personnel are not to be permitted in blow-down areas.
7. No maintenance is to be carried out in the blow-down area.
8. No section of the plant is to be blown down or run if its controlling dust collection system is inoperative.

   Machinery must not be re-started until the dust system is cleared and made operative.

   All heaps and excess of dust must be removed immediately.

9. Never disperse large quantities of heaped dust with an air jet. Always remove by hand tool or vacuum.

REMEMBER! Air blow-down is only to remove light films of dust where other means are not possible."

The rules as regards "no smoking" by visitors and employees in most areas are rigidly enforced. "No Smoking" signs are clearly displayed very widely throughout terminals and other silos. Whenever a visitor arrives at a terminal, he is informed of the requirement and the reasons therefore. Every new employee is also advised that smoking is prohibited inside the terminal buildings, rail hoppers, galleries and the like with an appropriate explanation as to the reasons.

The rules against smoking are policed continuously and any breaches attract instant dismissal.

Maintenance Activities, etc.

Many of these activities can be potentially dangerous so that a strict set of rules has been devised to avoid, as far as possible, any person creating a risk. Welding, soldering or cutting are strictly forbidden without prior advice to, and permission from, the Terminal or Silo (Elevator) Superintendent. The work is supervised by senior maintenance personnel. The area where the work is to be carried out is thoroughly cleaned and dampened down under the supervision of a senior staff member. An asbestos blanket and wet sacking is placed around and below the location of the cut or weld. A person whose duty it is to watch for a fire is in attendance both during and after the work has been performed and an adequate supply of fire extinguishers is suitably located for use, if necessary.

When welding and cutting or any other work of this nature has to be done, care is taken to ensure that the conveyors and other machinery, plus the dust system, are switched off and isolated.

Welding or cutting are not performed if work for the day is to cease within two hours. If either type of work has been done during the day the area is kept under surveillance for at least two hours after completion and a final inspection is made before employees depart at the end of the day. Also, where night watchmen are employed, they are advised if welding or cutting has been carried out and its location. As far as possible, every endeavour is made to do any of this potentially dangerous work in workshops away from the particular terminals. In New South Wales, the grain handling authority has introduced air operated hand tools in place of spark producing electric tools for maintenance work.

In 1977 and 1978, dust explosions in other parts of the world received considerable publicity in Australia. This has resulted in a greater awareness of the problem, and moves have been made to regularly test the level of dust in and around bulk grain shipping terminals and major country silos.

For an explosion to occur, it has been stated that the minimum critical concentration may be as low as 0·02 ounces per cubic foot (20·0 grams per cubic metre).

Chiotti, P. "An Overview of Grain Dust Explosion Problems". In Proceedings International Symposium on Grain Dust Explosions, Kansas City, Missouri, October 4-6, 1977

In Western Australia, the State Government Public Health Department had recommended that the bulk grain handling authority acquire a Mines Safety Appliance Gravametric Dust Sampling Pump, Model G, for the purpose of testing levels of dust. For some time, the State Government Public Health Department has been using this instrument in conjunction with the Department of Mines for dust sampling in the mining industry. The pump is a re-chargeable battery operated diaphragm unit with a sample flow indicator and a sample rate control valve.

In the Kwinana Grain Terminal, which is the largest terminal in Western Australia, readings taken recently were as follows:-

Shipping Gallery	75 mg per M^3
Rail Discharge Area	338 mg per M^3
Over-cell area - grain being discharged into cells	83 mg per M^3
Under-cell area - discharging grain	Zero
Loading grain into horizontal storage	67 mg per M^3
Truck collecting dust into dust house	3,900 mg per M^3

The Grain Elevators Board of Victoria has provided the results of some recent tests carried out in that particular system. Samples were taken at elevator heads, working house, etc., and produced the following results:-

Tandarra Silo	Maximum 272 mg per M^3
Mitiamo Silo	Maximum 389 mg per M^3

Static Electricity

Static electricity which is often regarded as one of the culprits in the causation of dust explosions arises because of the transfer of a static charge to isolated metallic conductors which are not grounded. However, for static electricity to pose a problem, four conditions should exist:-

1. An effective means of static generation.
2. A means of accumulating separate charges and maintaining a suitable difference of electrical potential.
3. A spark discharge of adequate energy.
4. A spark must occur in an ignitable mixture.

Before a dangerous arc can occur, the static electricity should reach the required minimum voltage, depending on the conditions prevailing at the time and usually around 30,000 volts.

The bulk handling authority in Western Australia has acquired a 3M 703 Static Meter Gun. Charges are detected by the utilization of a nuclear source (H3 "Tritium"), and a high resistance measuring element. The voltage read on the unit is the potential difference between the object under test, and the tip of the meter with reference to ground, providing the operator is grounded. The reading indicates both the voltage level and the polarity (plus or minus) of the charged surface.

Again a recent series of readings at the Kwinana Grain Terminal in April, 1978, disclosed the following:-

Conveyor Belts	Varied from zero to 200 volts
V Belts	Varied from zero to 20,000 volts
Elevator Head/Elevator Belting	150 volts
Mikropul Dust Collection Units (tests taken inside units)	
- Bags consisting of carbon impregnation of synthetic fibre	Zero
- Bags made of cotton fibre with copper earthing	Zero
Compressed air using nylon lance	2,000 volts
Identical unit replacing nylon lance with steel unit	Zero
Industrial vacuum cleaners	Varies from zero to 400 volts

Testing for static electricity build-up is now part of the regular routine of safety checking.

Cleaning as a Regular Routine

All too often cleaning is assigned to the occasion when there is no other work to be done. This tends to develop acceptance of a terminal as necessarily being a dirty or dusty place and if the pressure of work is constant, cleaning can be overlooked.

To ensure that cleaning is not overlooked or forgotten, the bulk grain handling authority in Western Australia has developed a system whereby this activity is performed as part of a regular routine. Cleaning schedules have been devised which enumerate the various sections of the terminal, categorising them as to whether cleaning is to be performed daily, weekly, monthly, quarterly or yearly. It is the responsibility of the Terminal Superintendent to see that the work is done as scheduled. The system has transformed cleaning from a "do it when you have time" operation into a regular and efficient routine.

The following is an example of a routine and in fact is the one used at the terminal on the shores of Kwinana, Western Australia:-

Daily

1. Floor areas surrounding Conveyors being used
2. Ship Loaders and Wharf
3. Dust Houses
4. Horizontal Storage Working House
5. Track Shed

Weekly

1. Boot Pit Main Working House
2. Undercell Area
3. Overcell Area
4. Track Shed Area and Rail Lines
5. Cockpit Windows
6. Overflow Bin Rooms Floors 1, 2 and 4
7. Trippers on Floors 7, 8, 9 and 10
8. Office Car Park
9. Radial Distributors
10. Automatic Samplers

Monthly

1. Roadways, Drains and Gutters
2. Transfer Galleries not in use
3. Horizontal Storage Tunnels
4. Weighers 1, 2, 3 and 4
5. Check Weighers
6. MIAG Distribution Bins
7. Clean out Empty Main and Star Cells

Annually

1. Shipping Galleries Roof and Walls (inside)
2. Track Shed Walls and Roof (inside).
3. Horizontal Storages

Safety Officers and Safety Committees

Each of the bulk grain handling authorities in Australia employs an officer who has the responsibility to ensure that all employees are aware of the need for safety. In most cases, these officers are engaged completely on safety duties which include all other aspects of safe working conditions as well as the avoidance of grain dust explosions.

Most of the officers concerned have received formal training in safety and visit port terminals and major country silos on a regular basis. They carry out detailed inspections of working conditions and draw attention to any areas needing improvement. There is little doubt that their activities have contributed to engendering a consciousness of the inherent dangers of dust. In this connection they have drawn on the unfortunate experiences of overseas countries as, whenever an explosion occurs overseas, photos and film clips are obtained and taken to the major grain installations to show the employees the potential hazards they face and to impress upon them the necessity for all the safe-working rules that have been instituted.

The Safety Committee concept has been developed to a considerable extent in Australia. In all of the terminals and silos where a reasonably large number of people are employed, these Committees are a useful way of promulgating safety messages and developing safety consciousness. There is little doubt that they have assisted in reducing the number of accidents and making employees aware that the rules for prevention of grain dust explosions are sound.

Usually, three or four persons comprise the Committee and they are encouraged to meet regularly to consider all aspects of safety policy implementation and discuss other matters affecting their working environment. The Safety Officer usually obtains a copy of the Minutes of their meeting and thus is kept fully informed of the occurrences at each point. The non-receipt of minutes of meetings is often a sign that the committee has become inactive and if this occurs, the Safety Officer can then take steps to get the members meeting and acting again.

In Australia, there has always been a considerable interchange of information between the bulk grain handling authorities in the various States on matters relating to safety. Recently, this spirit of co-operation was made even more manifest when the authorities jointly prepared a manual of codes of practice and safe operating procedures. This arose as the result of a request by a trade union for legislation on a number of safety measures. The bulk grain handling authorities were not in favour of legislation being imposed on the industry from without and were able to persuade the union to accept production of the manual as a compromise. The manual contains a section on grain dust which sets out the necessary guidelines for the averting of any explosions.

Insurance

In Australia, substantial insurance cover is taken out by each of the State bulk grain handling authorities to cover the major risks such as fire, storm, tempest, explosion, earthquake and impact damage.

Despite the ever present danger of fire and explosion in grain terminals and silos, which influences insurers in the establishment of their premiums, those in Australia have experienced very little in the way of claims due to the outstanding record of the various bulk grain handling authorities.

The six bulk grain handling authorities control approximately 1,000 installations but during the past ten years, there have been no more than six fires, including one minor explosion with none being very large in terms of insurance replacement cost. The largest claim is thought to have been in Western Australia, where during construction a fire was experienced prior to the silo becoming operational. Contrary to instructions, a welder used an oxy-acetylene torch to cut a hole in some elevator trunking and the hot metal caused an extensive conflagration. The cost to the contractor's insurers was $A500,000. However, this cannot be considered as an operational risk or claim.

While insurance rates vary in some instances, major cover at replacement values has been arranged through Australian underwriters at less than 10¢ per Australian $100.

Enquiries have been made overseas and comparisons of rates examined but the offers have not been comparable with Australian premiums or terms of cover. The Australian experience is that overseas insurers, when quoting, think in terms of overseas insurance claims experience.

Fire Suppression

While heat sensing devices are generally not installed in the grain terminals of Western Australia, consideration has been given to the action that would be taken if a fire was to break out in one of the vertical silos. Reports have been received that such an occurrence can take place and extinguishing the fire would create a considerable problem.

The bulk grain handling authority in Western Australia is examining the practicability of using CO^2 gas as an extinguishant for such an eventuality. As well as its extinguishant capabilities, CO^2 also possesses favourable cooling effects, is inexpensive and easy to acquire.

Working on the basis of 35% interstitial air space in wheat, the requirements for flooding a vertical cell at, say, the Kwinana Grain Terminal, is as follows:-

Cell capacity	2,997 cubic metres
Atmosphere to be displaced by CO^2	1,049 cubic metres
45% of displaced atmosphere	472 cubic metres
CO^2 gas required to flood cell	472 cubic metres
Weight of this volume	871 kilograms
Expansion rate of CO^2 from liquid to gas	1 kilogram = .542 cubic metres

An application point is to be fitted to the valve opening for the gas to be pumped in under pressure. If the proposal appears feasible, then some cylinders of CO^2 could be retained on hand for use in case of need.

Conclusion

All of the caution exhibited in Australia is well justified for, despite the excellent record in this country, the potential grain dust hazards are just as factual as they are in any other country.

Explosions in other parts of the world appear to have occurred over a wide range of temperatures, barometric readings and humidity levels. Australian conditions certainly fall within the ambit of that wide range and it is fallacious to assume that just because Australia has been fortunate so far, then it must have a climate which is not conducive to dust explosions.

There is possibly just as much dust in an Australian elevator leg as there is in an elevator leg in any other country. Also, there is little reason to assume that ignition temperatures in Australia would be significantly different to those experienced in other countries where a number of grain dust explosions have occurred.

For the purposes of this paper, some measurements of grain dust particle size were recently performed at the Fremantle Grain Terminal in Western Australia. The testing equipment used was a Gravometric Sampler Anderson Filter Grid and the grain dust was from oats.

It has been stated that the smaller the size of dust particle, the easier it is to ignite the dust cloud.

Boyle, A.R. and Llewellyn, F.J. "The Electrostatic Ignitability of Dust Clouds and Powders". Journal of Applied Chemistry, Vol. 69, 1950: pp 173 - 181.

Four of the samples taken at Fremantle were from airborne dust and four were taken at random from appropriate structures. With one of the samples, 30% of the dust fell within the range of 2 microns and another had 60% within the range of 5 microns. Most had 20% to 30% of their constituent dust in the 1 to 5 micron range.

These results seem to be approximately consonant with readings taken in other parts of the world so that a more favourable particle size does not appear to be a causal reason for Australia's fortunate record.

The one area of apparent difference is that corn is not handled to a significant extent in Australia by most bulk grain handling authorities and soya beans rarely, if ever. However, grain dust explosions have occurred in overseas terminals that have never handled these commodities so this does not appear to be a factor of any great relevance.

Whilst a number of Australian grain terminals have magnets for the removal of tramp metal at receival grids, the grain in this country is just as subject to admixture from foreign bodies as grain in any other country.

When a silo is devastated it is usual for the initial explosion to be closely followed by one or more secondary explosions of much greater intensity. The secondary explosions are obviously caused by the dust in suspension which is sucked into the area where the first explosion occurred. By ensuring that dust is kept to a minimum, Australian grain terminals and silos avoid the risk that a secondary explosion, if it did occur, would be a very big affair.

May 15, 1978

FIRE AND EXPLOSIONS IN A TERMINAL GRAIN ELEVATOR - CASE HISTORY AND EVALUATION

by

W.D. Liam Finn

INTRODUCTION

On October 3rd, 1975, at 9:55 a.m., a foreman in the Burrard Terminal Elevator, North Vancouver, British Columbia, telephoned the North Vancouver Fire Department to report a possible fire in the workhouse. Shortly afterwards, two explosions shook the building. The resulting fire destroyed the workhouse, trackshed, and a large portion of the shipping gallery. Damage from the fire is estimated to be of the order of $8,000,000.

At the time of the explosion twenty-six persons were working at the elevator. Only one person was trapped in the building. His body has never been found. While escaping from the building, some of the workers were seriously burned and four of them died later in hospital.

The writer was appointed by the Federal Minister of Labour in Ottawa to act as a one-man commission:

1. To hold and cause an inquiry to be made into the circumstances of the fire and explosions that occurred on October 3, 1975 in the workhouse of the elevators of Burrard Terminals Limited at 357 Low Level Road in the City of North Vancouver in the Province of British Columbia;
2. To hold and cause an inquiry to be made to examine the nature, causes, and circumstances of other recent occurrences of this kind that have caused employment injuries and/or damage to property and equipment in and about the terminal grain elevators on the British Columbia waterfront, to determine the causes of the fires and explosions and to submit its findings and recommendations to the Minister of Labour in the interest of improving the safety and protecting the health of the employees in and about the terminal grain elevators on the British Columbia waterfront.

To carry out the necessary investigations, the Commission was authorized to consult or procure information from any organization, individual or group of persons and was generally constituted with the powers under Part 1 of the Inquiries Act of Canada. The findings of the Commission (Finn, 1976) were reported to the Minister on October 7, 1976. The material in this paper is drawn from that report.

GRAIN HANDLING PROCEDURES

A general knowledge of grain handling procedures in terminal grain elevators is necessary to understand certain parts of this report. The following elementary description of grain handling provides the minimum necessary general knowledge.

In its simplest form on the west coast of Canada, a terminal grain elevator consists of a trackshed where the grain is unloaded from railcars, a workhouse in which the grain is processed, an annex of concrete silos for storing the grain, and a shipping gallery and dock for loading on ships.

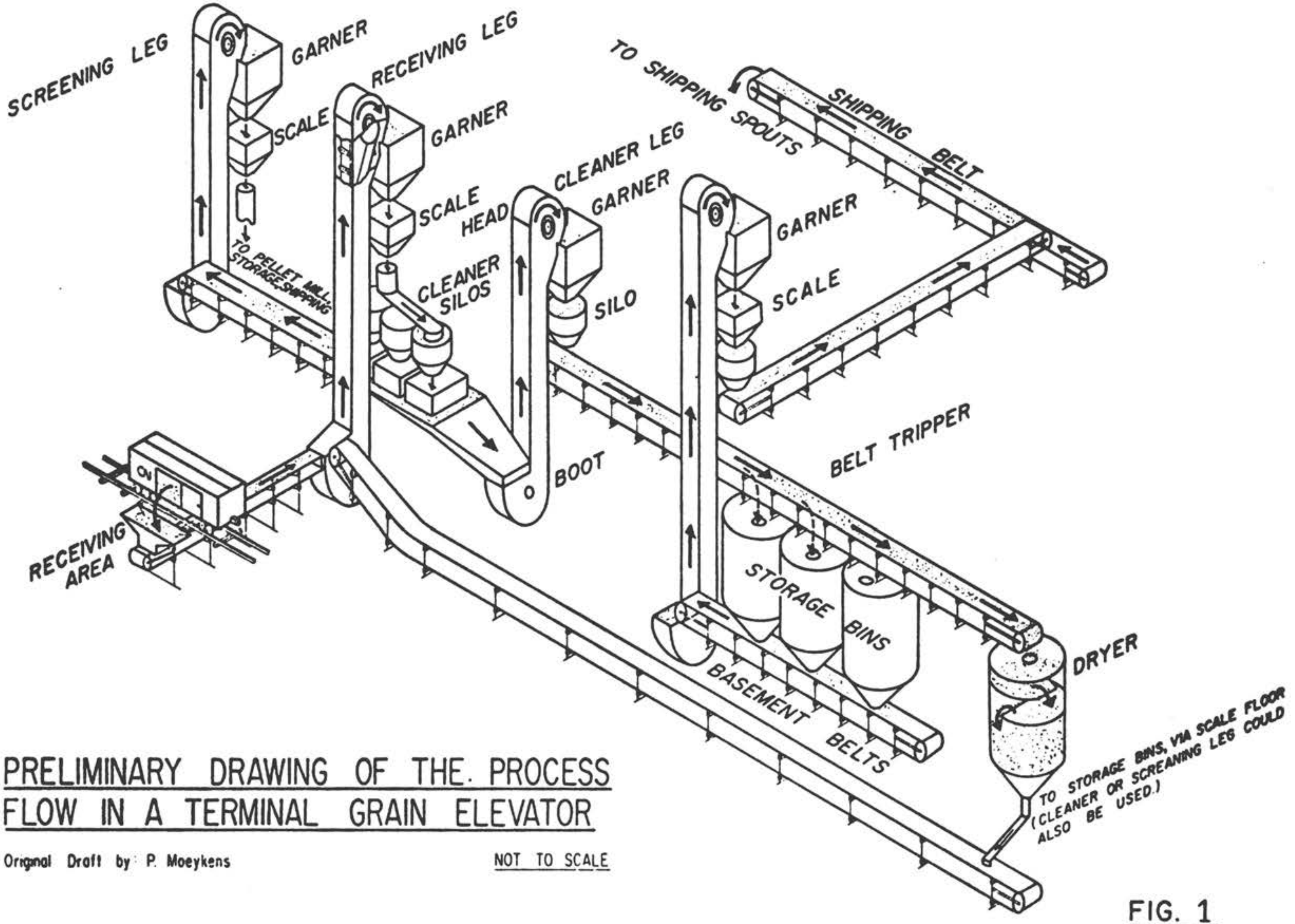
The workhouse is a tall structure, usually over 160 feet high, containing most of the equipment needed to process the grain, and prepare it for export. It contains elevating machinery, weighing scales, cleaners, and a number of temporary or working storage bins ranging in capacity from 1,000 to 10,000 bushels. The grain is elevated from the receiving area to the top of the workhouse from which it flows by gravity to be weighed and cleaned.

Conveyor belts connect the workhouse to the main storage bins. The bins are circular concrete silos, tangent to each other in rows. A typical bin might be 23 feet in diameter, 100 feet high, and have a storage capacity of 33,000 bushels.

The flow of grain in an elevator will be described with the aid of Figure 1 which, in a very general way, represents the principal features of the flow of grain through a terminal elevator. Grain from country elevators is transported either by hopper cars of capacity up to 3,400 bushels each or more frequently at the present time by box cars with individual capacities ranging from 2,000 - 3,100 bushels. The boxcars are unloaded in the trackshed receiving area, usually by car dumpers which tilt and rotate the cars to facilitate the flow of grain through the doors. The grain pours through a floor grating into a pit containing large tanks. A conveyor belt carries the grain away in a flow regulated by a gate at the bottom of the pit. From the pit the grain flows to the bottom of one of the receiving bucket elevators in the basement of the workhouse.

The buckets are attached to a vertical endless belt that goes around a drive pulley or bull-wheel at the top of the elevator and an idle pulley at the bottom. The belt and its buckets travel in enclosed shafts called legs extending from the bottom to the top of the workhouse; the buckets ascend in the front leg and descend in the back leg. The two legs are joined at the top by a hood enclosing the head pulley and at the bottom by a boot enclosing the idle pulley. The entire bucket elevator is also referred to as an elevator leg.

The grain flowing into the boot is scooped up by the buckets. As the belt passes over the drive pulley, the buckets are inverted to toss the grain into a spout from which it is directed downward on its path through the workhouse.



PRELIMINARY DRAWING OF THE PROCESS FLOW IN A TERMINAL GRAIN ELEVATOR

Original Draft by P. Moeykens

NOT TO SCALE

FIG. 1

From the top of the receiving leg the grain flows into a bin called a garner located above the weighing scale bin. The garner acts as a surge tank to store the grain temporarily so that the incoming flow is not interrupted, while the grain is weighed in batches in the scale below. When the grain flowing from the garner fills the scale bin, the gate at the bottom of the garner is closed. Then the weighman weighs the grain, and discharges it into one of the bins in the workhouse.

Grain Cleaning and Drying

Grain is released from workhouse bins through spouts which direct it to the cleaners. The cleaners separate from the grain chaff, straw, weed seeds, grain of another class, small lumps of soil, and small stones. The cleaning machines use either vibrating plane screens or rotating cylindrical screens.

Clean grain is conveyed to the boot of a cleaner leg in which the grain is elevated again to a garner at the top of the workhouse. From here, it flows by gravity to a horizontal belt conveyor which carries it to the top of the storage bins. The grain is diverted into the appropriate bin by a moving device called a tripper, which intercepts the grain stream on the belt and passes it through a spout positioned over the bin opening.

Many different types of dryers have been developed for both batch and continuous-flow drying. Hot air dryers now in common use depend on convection to carry heat to the damp grain and to remove evaporated moisture. All west coast elevators have drying equipment with a capacity of up to 1,000 bushels per hour per dryer for damp grain.

Shiploading

When loading a ship, grain of appropriate grade is discharged from a storage bin to a conveyor belt which carries it to the boot of a shipping leg that elevates it to the top of the workhouse for weighing and temporary storage into a shipping bin.

From the shipping bin the grain is discharged to a belt conveyor which carries it to the shipping gallery. Here, it is diverted into a spout which feeds it into the hold of the ship.

Disposal of Screenings

Screenings from the cleaners are conveyed to a screening leg by which they are elevated to a screening garner. They are then fed through different machines to separate them into different grades of screenings; e.g., No. 1 or No. 2 feed screenings, mixed feed oats, flax, rapeseed, and refuse screenings.

Refuse screenings are usually converted into pellets for sale in local or export markets. The other screenings are shipped by truck or railway car to supply the domestic market along the Pacific Coast.

INVESTIGATIONS BY COMMISSION

The Commission appointed a consultant to prepare a chronology of events in the elevator on the morning of the fire and explosion. This chronology was based on the reports of previous investigations and evidence before the Commission.

A summary of the consultant's report outlining the more important events, is as follows:

Chronology of Events

At 9:40 a.m. on October 3, 1975, bran pellets were being loaded onto the Russian ship "Anton Chekov" using the No. 1 shipping and receiving leg. The flow of pellets was stopped at the ship, and bran pellets began to back up and fill the No. 1 garner bin. The operator of the No. 1 leg signalled a worker in the basement to shut off the supply of pellets, and went to balance his scale for the next load. The warning light on the garner, indicating the danger of overfilling and thus jamming the leg, may have been on at this time. The operator in the basement cut off the bin feeding the conveyor belt to No. 1 leg, but the belt was allowed to run to clear itself as was normal practice.

A weighman, who was working No. 3 leg on the scale floor, went to listen to the sounds in No. 1 leg, and concluded it was still operating. He then went up in the man lift, called the humphry, to the head or top floor, and noticed the leg drive was still turning.

The elevator leg jammed, and the vertical bucket belt stopped about 9:43 a.m.

Two other workers on the scale floor decided to go up to the head floor to investigate. They noticed that, although the belt was stopped, the head pulley drive was still turning. They immediately shut off all equipment on the No. 1 leg. At this point, it is important to note that the head pulley had been turning against a stationary loaded belt for 1½ to 2 minutes. They opened the hood on the head pulley, and looked in. They saw no flames but smelt smoke. They now headed downstairs on foot to the millwright shop, which they reached about 9:50 a.m.

In the meantime, the foreman met an electrician and his helper on the cleaner floor and told them the No. 1 leg was plugged. They went up in the elevator to check the head pulley and drive motor. The foreman left for the trackshed to get a clean-up crew to clean out the plugged boot of No. 1 leg.

About 9:48 a.m., the electrician and his helper reached the head floor. They noticed that the hood was open. There was no fire but they felt heat and smelt smoke. They checked the switch on the head motor and, on finding it low on oil, went down the elevator to get some.

At about 9:50 a.m., a clean-up crew began cleaning out the boot of No. 1 leg. Note that the 170 foot high leg casing was open now at the top and bottom, and could act as a giant flue.

The operator of the No. 3 leg went up the man lift again to the head floor and noticed flames in the hood of the leg. He came down to the scale floor to report the fire, as there was no phone on the head floor. He then went back up to the head floor and began to shut down all the other legs and equipment. A millwright now arrived on the head floor and he and the No. 3 operator began to fight the fire using fire extinguishers. The millwright climbed up the leg for better access to the fire.

At this time, about 9:54 a.m., the sprinklers in the hood of the leg went on and sprayed water on the belt and pulley, and the sprinkler alarm sounded. Water dripped down the leg casing and was noticed on the scale floor. At this time, the operator of the No. 1 leg phoned the foreman in his office about the fire, and the foreman phoned the fire department. This call was logged at 9:55 a.m.

About this time, some workmen met outside the workhouse and heard the sprinkler gong. After a discussion, they decided to turn the sprinklers off.

Meanwhile, completely ignorant of what was happening on the head floor at the other end of the No. 1 leg, the clean-up team continued to dig out the bran pellets from the boot of the leg.

Shortly after the sprinklers were turned off, the operator of the No. 3 leg came down to the scale floor and told everyone to get out. He went back up again with the operator of the No. 1 leg to continue fighting the fire. It was now about 9:58 a.m., and the clean-up crew in the basement noticed sparks and burning pellets in the boot of No. 1 leg. The explosion occurred at about 9:59 a.m.

Tests on Belt from No. 1 Leg

A section of the belt from the No. 1 leg was recovered after the fire and showed no signs of fire damage. According to testimony, it had probably been protected by the grain in the leg. The belt had a rubber covering on the outside but was worn down to the canvas on the inside. The Commission requested the Consultant to run tension, ignition, and friction tests on this section of the belt. Briefly, the consultant's findings were as follows:

- the belt had a tensile strength of the order of 50% of that of a new belt;

- the canvas surface of the belt ignited in about 2 minutes, on the average, under heat inputs likely to result from belt slip. The rubber covered side took about three times as long, on the average, to ignite;

- the frictional resistance of the canvas side of the belt was less than that of the rubber covered side.

Analysis of Events and Testimony

(a) There was insufficient storage capacity left in the shipping system at the time the garner warning light was noticed to allow shutdown of the system and clearing of the belts without plugging. Either insufficient warning time was incorporated into the system or the warning light was not noticed immediately and some useful reaction time was lost. A horn system had been incorporated in the warning system to draw immediate attention to the danger of impending overfilling, but had been disconnected because it was considered an irritation.

(b) The head pulley continued to turn against the loaded stationary belt, although it was fitted with an overload control designed to shut off the system in such circumstances. This overload control had functioned according to design in the past; on this occasion, it did not. Therefore, either the control malfunctioned or the friction between belt and pulley was insufficient to develop the necessary overload torque. The consultant's tests indicated significant differences in frictional characteristics of canvas and rubber covered belts, and the Commission considers it probable that sufficient overload could not develop to actuate the control mechanism because of inadequate friction between belt and pulley.

(c) Although there was a smell of smoke or burning rubber at the head of No. 1 leg and, later, flames were noticed, the foreman was not notified until the fire had got out of control.

(d) Different workers inspected the head of No. 1 leg at various times, and each responded in accordance with his own assessment of the situation and not in accordance with a planned procedure.

(e) Means of communication in the elevator were limited and were, primarily, by word of mouth. One of the results was that those who left the head floor continued to operate on the basis of their original assessment and remained ignorant of the deteriorating situation.

(f) No attempt was made to warn those shovelling out the boot of the leg that a serious fire was raging on top.

(g) The flue effect caused by the open hood and boot seems not to have occurred to anyone, at any stage.

(h) The belt was adequate in strength for its function to raise the elevator buckets with a reasonable factor of safety, but had only about 50% of the strength of a new belt. The deteriorated state of the belt may have had an effect on the length of time it could burn before separating and falling down the leg.

(i) According to testimony, the sprinkler system seemed to be bringing the fire under control when it was shut off.

(j) Shutting off the sprinkler system caused a drastic reduction in fire-fighting capability on the head floor at a critical time and adversely affected conditions at the head pulley but, on the evidence and test data before it, the Commission could not make a conclusive determination as to the extent that shutting off the sprinklers affected the subsequent course of events.

(k) It was not satisfactorily explained to the Commission why the sprinklers were turned off. The Commission is convinced that this action would not have been taken had the workers known there was a fire on the head floor of the workhouse or if they had been properly trained how to act in such an emergency.

(l) No fire alarm was sounded or general evacuation order given, even after the fire department had been called. It seems that only the No. 3 operator in his area on the scale floor, told people to get out.

(m) The evidence leads to the conclusion that much static dust lay around the elevator and contributed to the propagation of the explosion.

SOME FINDINGS OF THE COMMISSION

The proximate physical cause of the Burrard Terminal Elevator fire was the frictional heat generated when the head pulley in the jammed No. 1 elevator leg continued to turn against the stationary leg belt.

The overload control on the drive motor designed to shut down the leg in the event of jamming was not activated, probably because the belt was worn to the extent that it was unable to develop sufficient frictional torque.

The explosion occurred when the burning leg belt ignited an explosive mixture of dust in the confined space of the elevator leg.

The major factors contributing to loss of life and the large number of injuries were:

- there was no emergency plan;
- there was no general fire alarm system;
- there were very poor means of communication within the elevator;
- the workers were untrained in recognizing and coping with the special hazards posed by fire in a grain elevator.

These factors prevented the workers from acting as a cohesive, informed group in the emergency they faced, and resulted in many workers remaining ignorant of the existence of the emergency, until engulfed by the explosion.

It was not satisfactorily explained to the Commission why the sprinklers were turned off during the fire. The Commission is convinced that this action would not have been taken had the workers known there was a fire on the head floor of the workhouse or if they had been properly trained in how to act in such an emergency.

GRAIN DUST EXPLOSIONS: OCCURRENCE AND PREVENTION

The 1975 explosion at the Burrard Terminal elevators described earlier in this report, provides a graphic example of what can happen in a grain elevator when an explosion occurs.

An explosion will occur when the concentration of grain dust in the air exceeds a certain minimum level called the lower explosive limit (LEL) and there is a source of ignition.

Statistics on the frequency with which various sources of ignition cause fires were reported in the January 1976 issue of Grain Industries Plants (1976) as follows:

> *"CLEAN PLANTS seldom burn! stresses the importance of the relationship between "good housekeeping" and fire prevention... The following are some statistics on how a fire might start at your facility:*

20% Electrical: The trouble arises from lack of proper maintenance of equipment, or from the use of wrong type equipment in hazardous areas.

15% Friction: Hot bearings, misaligned or broken machines and in legs in particular.

10% Open Flame: Cutting and welding torches, coffee warmers, gas and oil burners, misuse of gasoline and similar torches ...

9% SMOKING & Matches: Remedy is prohibition in such areas, with smoking permitted only in safe places under regulations understood by all --- and rigidly enforced.

8% Spontaneous Ignition: Oil waste and rubbish, deposits in ducts and flues, storage of low-grade flammable materials.

7% Hot Surfaces: Fires resulting from combustibles exposed to the normal heat from driers, boilers and furnaces, hot ducts of flues, electric lamps or irons.

4% Overheated Materials: Caused by abnormal temperatures involving such things as heated flammable liquids -- and foreign materials in driers.

2% Static Electricity: Includes fires communicating from nearby properties, and fires caused by molten substances, lighting, chemical action, and incendiarism."

It is clear that electrical equipment and friction are the most common courses of ignition.

Friction heat is most often generated by slippage between a drive pulley and a belt. Minimum speed detectors should be installed on all legs and conveyor belts that would automatically shut down the system in the event that belt speed drops below a pre-determined level due to slippage.

To prevent the health and safety problems that may arise when one part of a system ceases to operate, all elevator legs, conveying systems, and dust control equipment should be interlocked so that in the event of any part of the system ceasing to operate the entire system shuts down. This would prevent the kind of occurrence the Commission noted on one occasion, when an elevator leg and its associated conveyor belts were operating, although the dust control system had broken down.

Further protection against ignition is provided by non-inflammable belts of polyester material. Some of these belts are already in use in elevators on the West Coast. Manufacturers claim that such belts are non-ignitable when held stationary against a rotating pulley.

Many potential sources of ignition can be eliminated by regular inspection and maintenance programs, adherence to good working practices and conformity to the relevant regulations.

Apart from a source of ignition a sufficient concentration of grain dust in the atmosphere is also required for an explosion.

The N.F.P.A. Fire Protection Handbook, 13th edition (1969) gives the lower explosion limit (LEL) of grain dust as 0.055 ounces of dust per cubic foot or 55,000 mgm per cubic meter. It is obvious that the concentration of dust to create an explosion hazard is many times higher than the regulatory threshold limit value of 10 mgm per cubic meter of total dust allowed by health standards. However, the dust concentrations (measured for health purposes) in elevators are usually averages over an eight hour day and, in order to be more meaningful from the explosion hazard point of view, the dust concentrations should be measured at dust release points over much shorter periods of time. Whereas, on the average, no explosive mixture of dust may be present in a particular place, from time to time concentrations above the lower explosion level may be present.

It is relevant, at this point, to mention a procedure used by the elevator companies for dislodging static dust from ducts, ledges and other surfaces in British Columbia prior to the Commission hearings. This procedure involves the use of compressed air and is commonly called "blowing down". Although direct evidence is not available, the Commission considers it probable that explosive concentrations of dust exist in the air during "blowing down". Labour Canada has since issued a directive prohibiting "blowing down" unless elevator operations are shut down.

Dust control systems with adequate capacity which are properly installed and maintained can be quite effective in controlling dust. The Commission was impressed by the dust control system at Neptune Terminals in North Vancouver, B.C. This is a bulk terminal handling coal and potash, but which has also handled grain on one occasion. The Commission noted the absence of coal dust in the area of the car dumpers due to a highly efficient vacuum system, which picked up the dust as soon as it was generated.

In the interest of obtaining experience with other systems the Commission travelled to Seattle and Tacoma, Washington, where it witnessed entirely enclosed and automated systems. The Commission recognizes that the system of grain handling in these terminals is substantially different from the Canadian method in that the grain is not cleaned in the elevators. However, the relative absence of dust in the elevators visited by the Commission in Washington State is testimony to what can be accomplished in this respect by modern design and technology.

Enclosing conveyor belts appears to be the most effective way of reducing airborne dust and, hence, of avoiding accumulations of static dust with their dangerous potential for explosion propagation.

In the present Canadian West Coast elevators, continuous effective housekeeping is essential to prevent dangerous accumulations of static dust. Testimony shows that housekeeping is normally delegated to the most junior employees and cleaning up is low on the scale of importance to elevator management. Whenever production presses or absenteeism occurs, members of the cleaning crews are reassigned to other duties. The result is that the system of housekeeping is extremely haphazard, spills are often not cleaned up when they occur, and static dust builds up to substantial levels.

Grain dust can generate high explosive pressures, and large areas are required to vent the hot gases before dangerous pressures are reached, in order to minimize the effect of explosion. There is no unanimity amoung authorities as to an acceptable minimum standard for venting areas but, generally, they are of the order of 1 sq.ft. for every 50 - 80 cu.ft. of room volume.

The National Building Code of Canada (1975) requires explosion venting to the outdoors of not less than 1 sq.ft. for each 50 cu.ft. of room or building volume, with the vents designed to release at a pressure not more than 20 p.s.f.

In some existing elevators it may be difficult to meet acceptable explosion venting standards, but every effort should be made to make existing vent areas as effective as possible by proper design and to extend venting areas where practical.

Existing Canadian Government regulations, if followed and enforced, would significantly reduce the probability of grain dust explosions. To further reduce that probability the Commission recommended that

(14) all bucket elevator legs and belt conveyors should be equipped with minimum speed detectors which will shut down the legs or belts automatically when the belt speed drops below some predetermined value due to belt slip;

(15) all legs and associated conveyors and dust control units should be interlocked so that, if one part of the system ceases to function, the entire system is shut down automatically;

(16) all elevator legs should be vented through the roof;

(17) sprinklers should be installed in all elevator legs;

(18) garners should be fitted with high level devices to shut down the system if garner overflow is imminent;

(19) all conveyor belts should be fitted with a stop pull cord for the entire length of the conveyor so that in the event of malfunction for whatever reason, the operator can stop the conveyor belt immediately. The stop mechanism should be of a type that prevents the belt from being restarted, until the actuator has been reset into the running position;

(20) heat sensors should be installed in locations that are subject to periodic overheating, such as hammermills, in order to give appropriate warnings of a dangerous condition;

(21) all conveyor belts and V-belt drives to be installed in grain elevators in the future should be non-inflammable and be approved for non-inflammable construction.

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METHODS FOR EXAMINING ELECTROSTATIC IGNITION HAZARDS

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1. INTRODUCTION

The assessment of electrostatic ignition hazards requires an understanding of the electrostatic processes occurring, or likely to occur, in particular situations and the ability to relate these processes quantitatively to safety criteria. Practical interest centres around the selection of actions to avoid hazards. The aim of the present paper is to give a brief summary of safety criteria, and to outline ways in which hazards may be assessed and routes identified to help their avoidance. Examples from work on silos and on tank washing in crude oil tankers are used to illustrate the methods of observation described.

2. SAFETY CRITERIA

Ignition of many common hydrocarbon vapour air mixtures under optimum conditions is achieved with a spark discharge of about 0.2 millijoules. (Lewis and von Elbe, 1961) This applies with metal electrodes. To avoid quenching, the breakdown gap needs to be larger than about 2 mm - which means a breakdown voltage above about 5 kV. Airborne suspensions of dusts require appreciably larger minimum ignition energies, typically in the range 10 to 100 millijoules. If significant concentrations of hydrocarbon vapours are present with these suspensions, due for example to microbiological action, then minimum ignition energies around 0.2 millijoules will apply.

For electrical discharges between a projection and a charged dielectric fluid or solid to ignite common hydrocarbon vapour air mixtures, the potential of the charged surface needs to be above some figure between 20 kV (Bright, 1978) and 45 kV (Strawson and Lyle, 1975) - with 35 kV (Dinham 1977) appearing as a plausible consensus figure. The most sensitive radius of curvature is about 12 mm.

Electrical breakdown of air at ambient temperature and pressure occurs when the field strength locally exceeds about 3000 kV m^{-1}. If at the same time the mean electric field across the whole gap between electrodes (expressed as total voltage difference divided by the gap) exceeds a figure around 500 kV m^{-1} it is likely that a spark discharge will bridge across the gap. If the mean field of 500 kV m^{-1} is not reached then the gap will only partially breakdown, and a corona or brush discharge will occur. Similar electric discharge characteristics will be observed in dusty atmosphere and in flammable gas mixtures.

Corona discharges are usually non-incendive, but if the potential is above about 65 kV and the projection has a radius of curvature near the optimum value of 12 mm then ignition can occur. (Van der Weerd, 1972)

If the electric field within a highly charged cloud locally exceeds 3000kV m^{-1} and there is an electric field above 500 kV m^{-1} over a scale distance of perhaps 3 to 5 m then it seems likely that a mini-lightning discharge could arise from the cloud. Such a process has not yet been demonstrated experimentally (Boschung et al 1977) but if it occurred in practice would be likely to involve a discharge of many joules of energy - sufficient to directly ignite flammable dusts.

The above discussion illustrates that the features of direct interest in describing the "electrostatic conditions" for a situation are electrostatic potentials and electric fields. The significant values depend upon the mechanism of ignition which may be present, and may be summarised very roughly as in Table I for common hydrocarbon vapour air mixtures:

TABLE I

Electrical discharge situation	Minimum Voltage (kV)	Peak local electric field needed (kV m^{-1})	Mean electric field over gap (kV m^{-1})	Minimum discharge energy (mJ)	Most sensitive radius of curvature (mm)
Metal to metal	5	3000	> 500	0.2	?
Metal projection to charged dielectric	35	3000	> 500	?	12
Metal projection to charge cloud	65	3000	< 500	?	12
Mini-lightning discharge	> 1500 ?	3000 (in cloud)	> 500	-	-

3. OBSERVATION AND INTERPRETATION OF ELECTROSTATIC CONDITIONS

Rotating vane fieldmeters are the most used and most useful instruments for observing electrostatic conditions in practical situations. (Van der Weerd 1971, Pollard and Chubb 1975) If flush mounted at a conducting boundary a fieldmeter gives a direct measurement of the electric field at that point. If lowered into the volume of a tank or silo where there is a distribution of potential and some distribution or charge, the fieldmeter reading will relate to the potential at the fieldmeter head position in the absence of the fieldmeter. (Van der Weerd 1971, Pollard and Chubb 1975) For a fieldmeter head of 100 mm diameter, mounted fairly well away from any earthed structures, the reading relates to the local potential as 11 kV m^{-1} per kV, with only a small influence from the ambient electric field.

Potential distributions obtained from fieldmeter traverses may be used to develop and check quantitative models for the distribution of charge density and potential. Potential distributions can be predicted analytically for only a few fairly basic geometric structural shapes with simple distributions of charge density. (Carruthers and Wigley, 1962) More complex structural shapes with a wider variety of options in the distribution of charge density and surface potential need the application of iterative computing techniques. The computer programmes POTENT (Thomas, 1973) and THREED (Thomas, 1974) developed at Culham, are particularly suitable for analysis of two and three dimensional systems. During the washing of cargo tanks with high pressure water jets a fine electrostatically charged mist is generated. (Van der Weerd, 1971) It seemed likely that due to aerodynamic stirring by the jets the charge density would be fairly uniform in the tank. During shipboard studies we have made fieldmeter traverses a short time after the cessation of washing and Figure 1 shows such a traverse compared to the curve calculated on the basis of a uniform charge density. (Chubb et al, 1976) Comparisons of this type confirm the model of a fairly uniform charge density and the ability to relate computed values quantitatively to practical observations. From such work, relationships can be derived for the mean charge density in the tank, the maximum space charge potential and potential and field values anywhere else in the tank in terms of a fieldmeter reading at a normal fixed mounting position.

Figures 2 and 3 show potential distributions we obtained in studies on a large food product silo during filling and shortly after filling was stopped. Comparisons to the potential distribution calculated for a uniform charge density show that charge densities were actually rather non-uniform. More appropriate models could be developed with further calculations. The experimental curves in Figures 2 and 3 were sufficient for interpretation of fieldmeter readings at the normal fieldmeter mounting positions to give values of maximum space charge potential within the volume of the silo.

An important aspect of practical electrostatic observations is the correlation of electrostatic conditions to operational features. This requires fieldmeter equipment able to operate continuously for extended periods in conditions which may involve high humidity, splashing water, dust, dirt, corrosive materials and flammable vapours. Fieldmeters we have developed (Pollard and Chubb, 1975) have been used successfully for continuous observations in the presence of high pressure water jets during tank washing studies, and for continuous observations in studies on a large food product silo. During such studies the fieldmeter output signals are recorded on an ultra-violet recorder and correlated with clock time and other parameters relating to practical operations.

Figure 4 shows an example of a sudden voltage excursion observed during studies in a silo. Examples such as this were interpreted as indicating maximum space potentials exceeding - 100 kV. Comparison to the safety criteria in Table I shows that such potentials are well above the minima needed for hazardous discharges involving charged dielectric surfaces and discharges between projections and charged clouds. The potentials may be below those needed for the occurrence of mini-lightning discharges - but the criteria for such events are not yet very well understood.

4. OBSERVATIONS OF ELECTROSTATIC DISCHARGES

Appreciation of the significance of observations on electrostatic conditions can be materially helped by correlating such observations, and observations on plant operation, to the occurrence of electrostatic discharges. The type of electrostatic discharge relevant to ignition (as discussed in Section 2) is either a spark discharge or the type of corona or brush discharge which has a well developed stem with a high local deposition of energy. The occurrence of such discharges can readily be monitored at a distance by radio observations. Radio observations using suitable aerial and receiver systems at a frequency around 40 MHz are sensitive to spark-type discharges with energies down to well below the minimum energy for ignition of common hydrocarbon vapour/air mixtures. (Chubb, Erents and Pollard 1973, Chubb 1974) Such observations are fairly insensitive to corona discharges which are non-incendive. Although it should be feasible to extract information from radio signals which would characterise the discharge and the dimensions of structures associated with the discharge (Butterworth, 1976) this is not in general a readily usuable technique. Signal amplitudes at any individual frequency do not relate to any directly relevant parameters of the discharge. The most useful application of radio monitoring is thus to indicate whether or not spark type discharges are occurring. In our observations two receiver systems are mounted well apart in the region under study and two further receiver systems are mounted to observe radio signals in the local environment. (Chubb 1974, Chubb 1975) Significant spark discharge events are only considered to occur when coincident signals are observed on the two internal aerials without signals present on either outside aerial. Figure 5 shows an example of fluctuations in fieldmeter signals and to timing of the occurrence of sparks during studies of tank washing. From such observations it was directly possible to attribute the occurrence of sparks with interaction of the washing jets in particular ways with a main longitudinal girder in the ship's tank.

During shipboard studies into tank washing the output signals from the radio coincidence checking circuits were used to trigger flash photographic equipment mounted in the cargo tanks. (Chubb et al 1976, Chubb 1975) Figure 6 shows an example of one such automatically triggered photograph. The first aim of this photography was to demonstrate the ways that sparks could actually occur during washing and to obtain information on the sizes and locations of lumps of wash water likely to be responsible for the occurrence of individual sparks so that the energies involved could be estimated from computer modelling studies. (Chubb, 1975) The second aim was to try to identify common features in the alignment of the washing jets or the behaviour of the wash water which could perhaps be avoided by changes in the design or operation of the washing equipment.

5. CONCLUSIONS

The methods described have proved helpful in observing and interpreting electrostatic processes associated with a number of investigations of electrostatic hazard situations.

Studies are needed to improve definition of the various hazard criteria - particularly the criteria relating to the possibilities for occurrence of mini-lightning discharges. Laboratory work is also needed to give a better understanding of charge generation and relaxation and for developing observational techniques. It is suggested however that the most important action needed is to identify all the plausible ways in which ignition hazards can arise in the normal operation of elevator systems and to check how well design, operating procedures, maintenance, inspection, etc ensure avoidance or suppression of hazard mechanisms. Electrostatic sparks are one possible ignition mechanism, and the approaches outlined in the present paper will enable the chance of such hazards to be assessed in practical operating plant.

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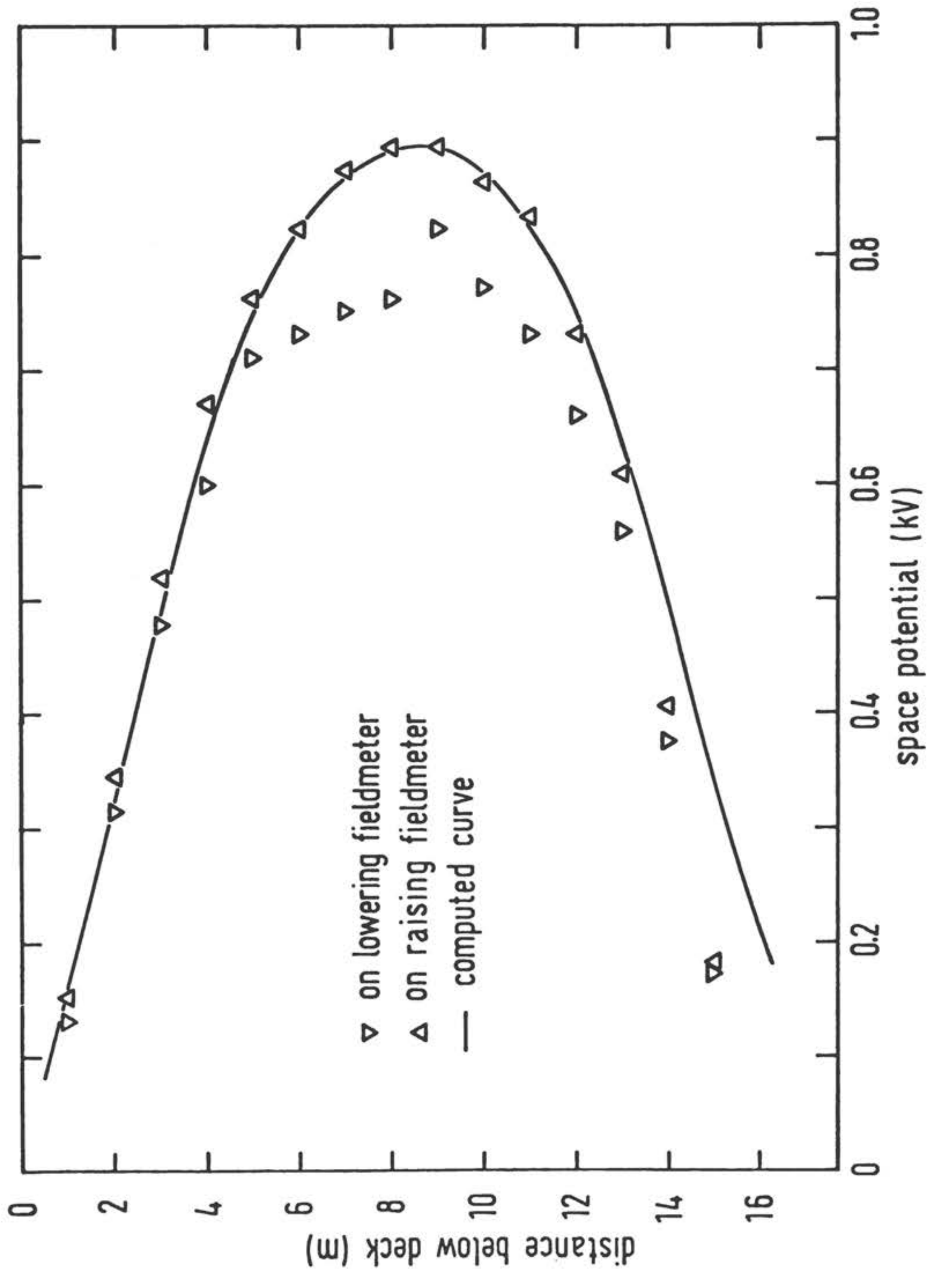

Figure 1: Comparison between fieldmeter observations during tank washing studies and computed distribution with uniform charge density.

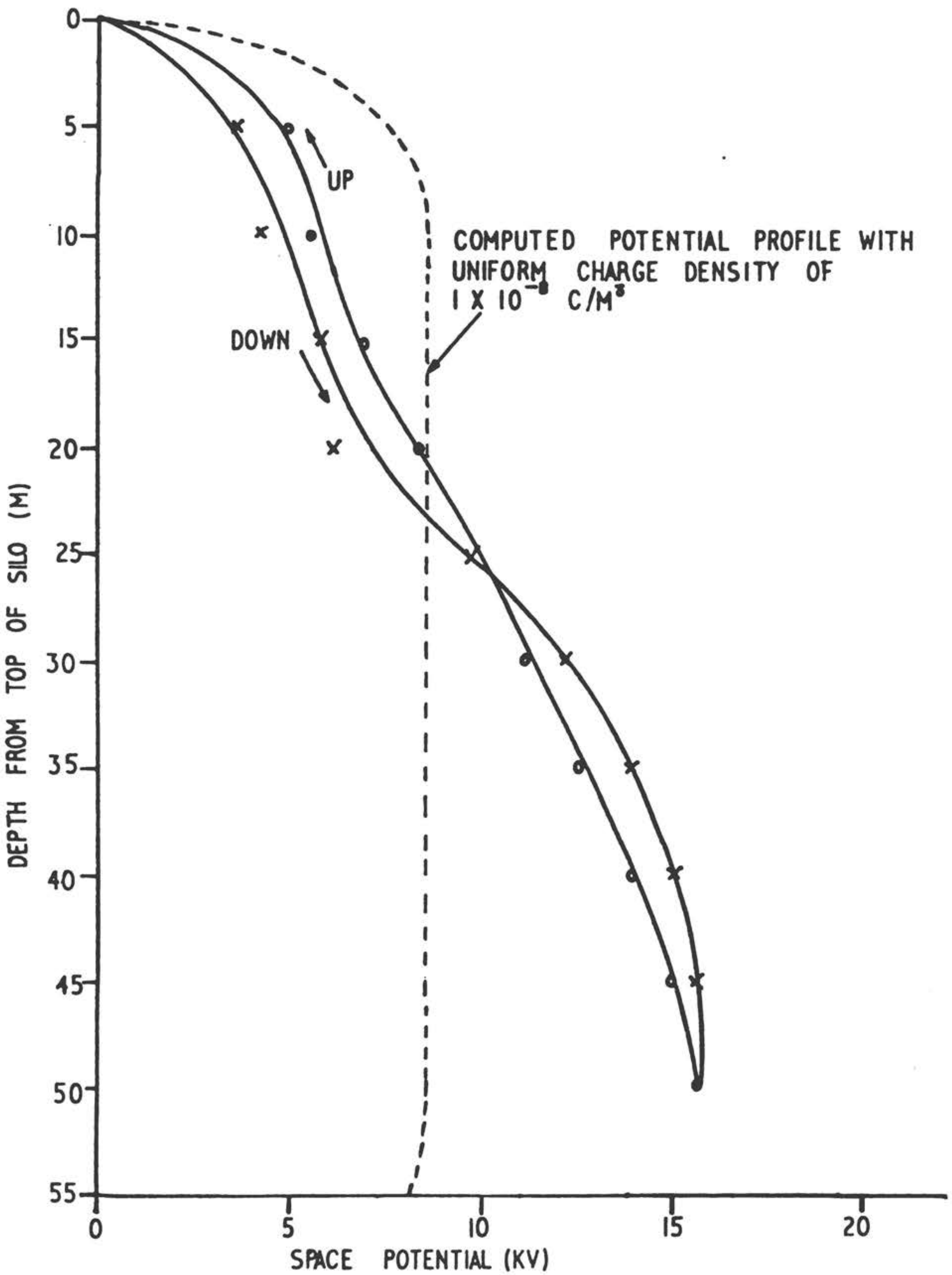

Figure 2: Potential profile in silo with feed entering.

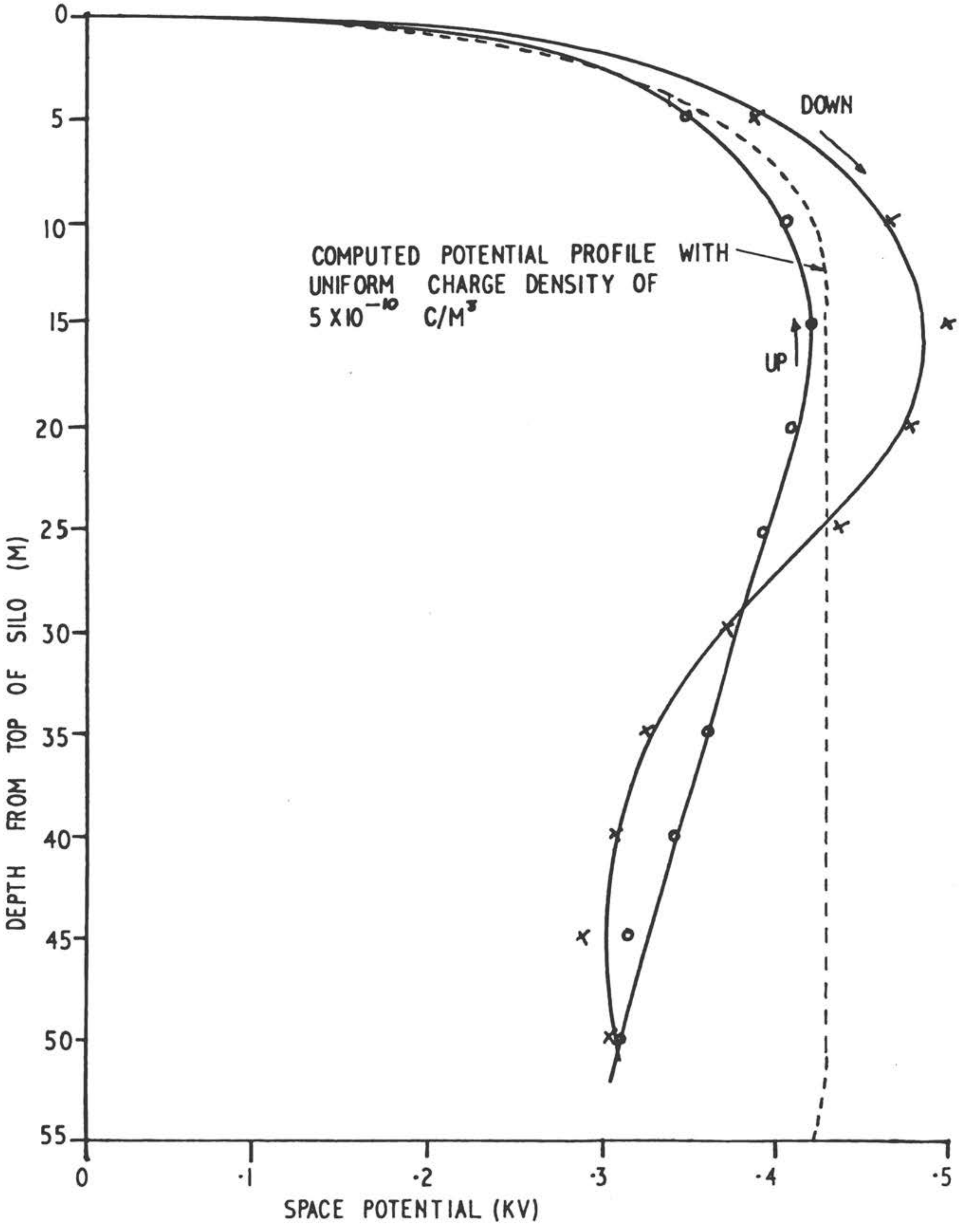

Figure 3: Potential profile in silo without feed.

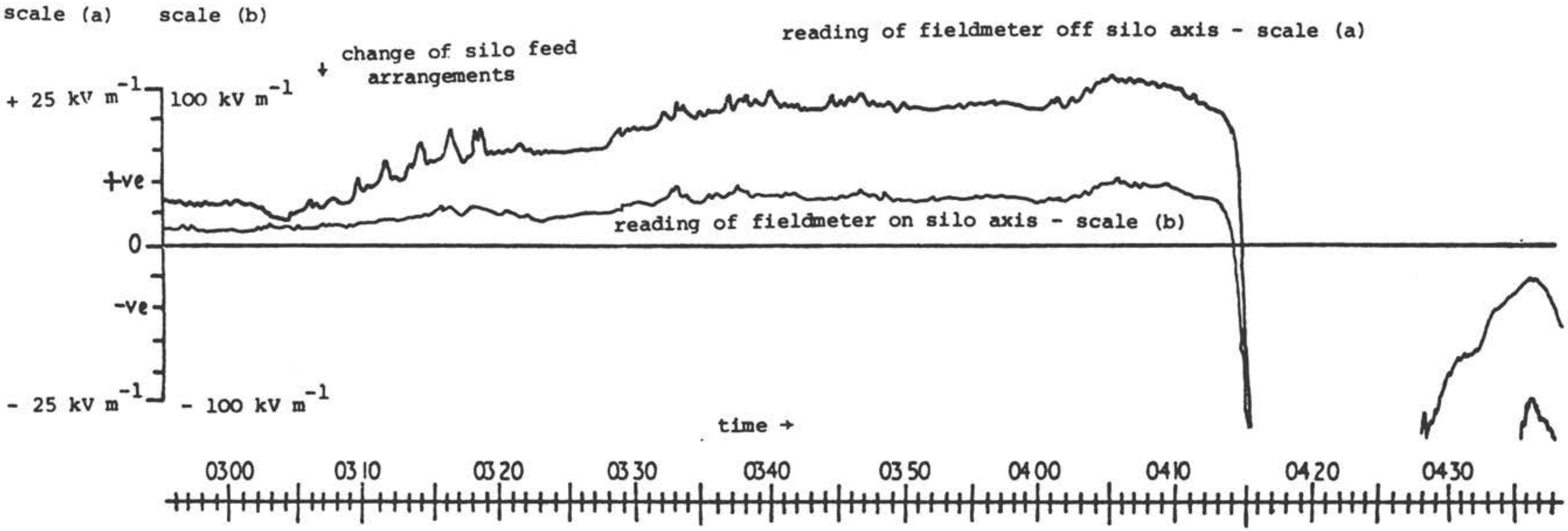

Figure 4: Example of voltage excursion observed during silo operations.

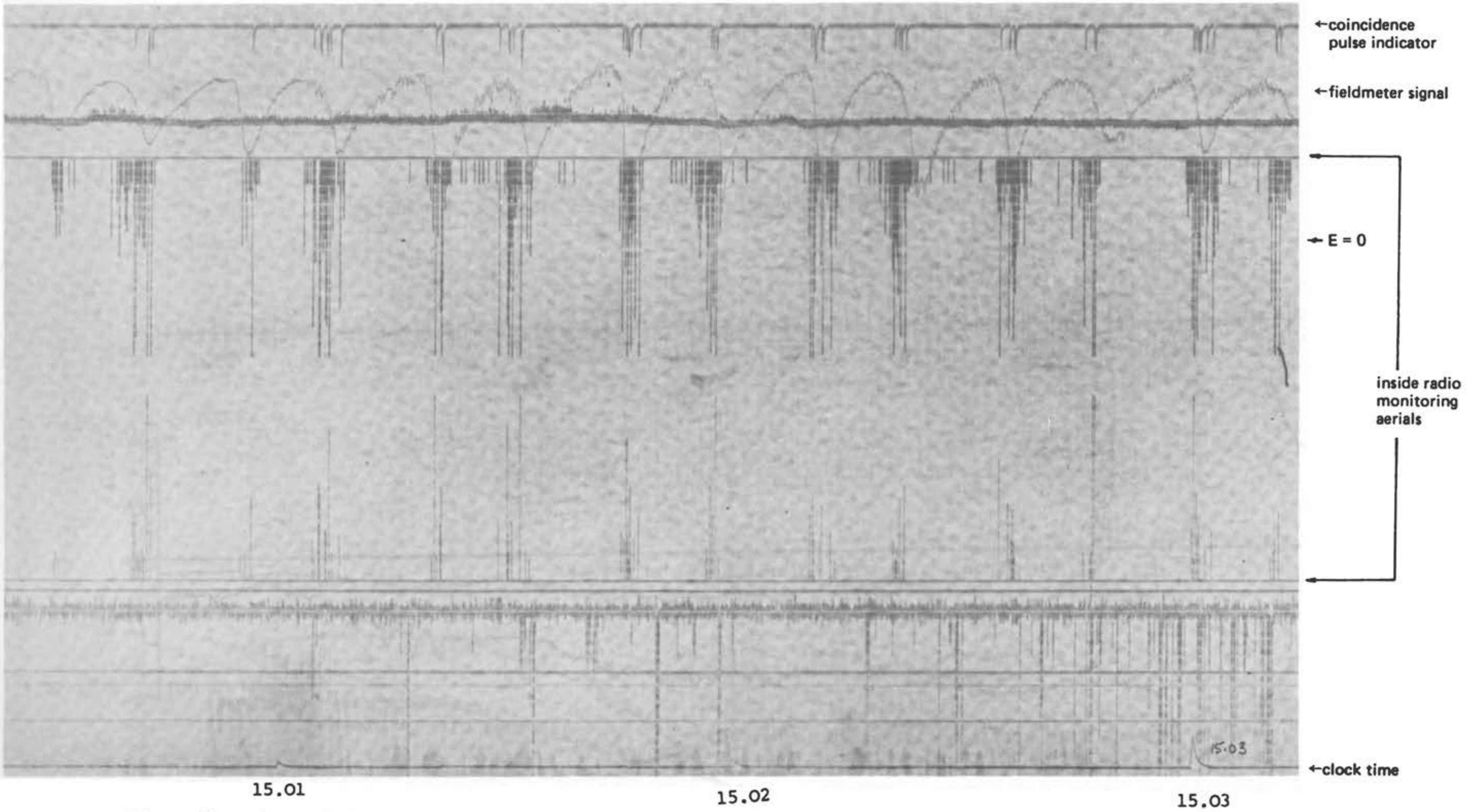

Figure 5: Ultra-violet recorder trace of fieldmeter and radio signals during washing operations with portable machine on 'British Centaur', 16 December.

Figure 6: Example of flash photograph triggered automatically by occurrence of an electrostatic spark during tank washing studies on 'British Purpose', May 1977.

Electrical discharge situation	Minimum Voltage (kV)	Peak local electric field needed (kV m^{-1})	Mean electric field over gap (kV m^{-1})	Minimum discharge energy (mJ)	Most sensitive radius of curvature (mm)
Metal to metal	5	3000	> 500	0.2	?
Metal projection to charged dielectric	35	3000	> 500	?	12
Metal projection to charge cloud	65	3000	< 500	?	12
Mini-lightning discharge	> 1500 ?	3000 (in cloud)	> 500	-	-

THE ANOMALY OF VERY DRY ATMOSPHERIC MOISTURE CONDITIONS AND AN INSIGNIFICANT INCIDENCE OF ELEVATOR DUST EXPLOSIONS

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SUMMARY: South Africa experiences very low relative humidities but has a negligible incidence of elevator explosions. Detailed information is presented on relative humidity and temperature conditions in the grain producing areas. The possibility that specific humidity could be significant is also considered.

INTRODUCTION

South Africa produces approximately 10 million ton of maize and 2 million ton of wheat annually in addition to smaller crops of grain sorghum, sunflower and ground nuts. The crops are harvested, transported stored and distributed internally and to export markets in bulk. We know of only three minor explosions which took place in bucket elevators and were caused either by bearings running hot or welding accidents. South Africa has been so free of dust accidents that the subject has not until now received particular attention.

The situation is, however, interesting in that the country experiences such low relative humidities that in terms of the regulations pertaining in some countries a high explosion hazard could be anticipated. This has not been the case and one wonders whether relative humidity as such is a major factor or whether there are other circumstances which have accounted for South Africa's relative immunity. We do not know. All we can do is to detail the conditions under which grain is handled and stored in the belief that this will contribute to the informed summary of opinion which is the objective of this symposium.

GENERAL

The main grain production area of South Africa is concentrated on a plateau, the Highveld, lying just south of the tropic of Capricon. The climate is tempered by the average altitude of 1500 m. Rain falls mainly in the summer from October to March. The winter from June to August is dry and there is no snow. Days are warm and sunny but frost is common at night. Maize, the main crop, is harvested in June, July and August while wheat is harvested in the rainy season in November and December. Relative humidities are low with the means of annual daily lowest values in the order of 36%. Winter lows of 10% are not unknown.

As can be expected the maize dries rapidly in the field and while the maximum moisture content for storage permitted by regulations is 14% during dry winters grain moisture content drops to as low as 10% at harvest. Drying of maize is limited and rarely from more than 20% but at least 50% of the wheat crop is dried in order to facilitate earlier harvesting at a time of the year when hail and thunderstorms are a hazard.

The distribution of the principal storage facilities is indicated in Fig 1.

RELATIVE HUMIDITY

A broad indication of winter atmospheric conditions can be obtained from Fig 2 - Monthly mean relative humidity at 14h00 for the months of July and September. In July the bulk of the grain producing area lies in the 30% to 40% relative humidity zone while in September, shortly before the start of the summer rains, in the 20% - 30% zone.

The diurnal variations can be assessed from Table 1 - the mean hourly values of relative humidity and temperature for the month of July for four weather stations in the Highveld grain producing area and from Fig 3 which depicts a typical day. The pattern is consistent with the relative humidity dropping below 45% after 10h00 when the temperature rose above 10°C. The sharp drop in temperature at dusk results in a rise in relative humidity.

In order to obtain an indication of extreme values the driest winter months since 1963 were selected at Jan Smuts airport near Germiston and proved to be August 1976 and July 1977. The driest days were then selected and the relative humidities are tabulated in Table 2.

On June 25 and July 21, 1977 the relative humidity was below the critical 45% for the full 24 hours and dropped to as low as 08% at 15h00 on July 21 when a temperature high of 19,7°C was recorded.

August 13 1976 was a colder day with a low of -2,3°C and a high of 13,4°C but from 10h00 to midnight the relative humidity was below 45%.

The humidity and temperature patterns must now be clear and it is evident that the very low day time relative humidities are due to relatively high temperatures. It does mean that during daylight hours, when the elevators are operating at full capacity, low relative humidities are normal and in extreme cases can be very low.

It must be mentioned that temperature and relative humidity data were obtained from official weather records and the instruments were housed in standard Stevenson screens. Recordings were not made in elevators but the data is considered typical of the Highveld.

We have emphasised dry conditions and limited data to stations with long term hourly records. In order to provide a wider background average 08h00 and 14h00 relative humidities are tabulated by month in Table 3 for a number of towns. The towns range from Piet Retief in the more humid East to Hoopstad in the drier West. It will be noted that even in the rainy season relative humidities are low.

Hoopstad, a wheat and maize producing district averages below 45% RH at 14h00 throughout the year. Potchefstroom, where research on summer cereals is concentrated, and an important production area, is similar.

It is quite obvious that if a relative humidity of less than 45% is regarded as a hazard limit then on most days on the Highveld in South Africa, summer and winter, this limit is reached.

SPECIFIC HUMIDITY

Despite the low relative humidity values experienced South Africa has been fortunate in not having experienced significant explosions. It is appreciated that the physical processes associated with static electrical discharges and the propagation of dust explosions are complex and that the rôle of water vapour in these processes is difficult to quantify but one wonders if the hazards could be related more to the specific humidity (mass of water per unit mass of air) of the air rather than to the relative humidity?

The area we are considering lies at an average altitude of 1500 m and this must be considered when relating specific humidity to relative humidity. For the purpose of the following approximations an average atmospheric pressure of 80 kPa has been assumed and values obtained from a psychometric chart.

Experience with natural air drying has shown that the specific humidity is normally in the order of .004 in winter and .012 in summer.

A closer examination of the selected dry days included in Table 2 discloses that very low specific humidity levels are attained. The 14h00 readings on June 14, 1977 (RH 10%, 17,7°C) are equivelent to a specific humidity of .002. July 21, 1977 is of the same order at 14h00 but somewhat higher viz .003 at 07h00.

It can be assumed that specific humidities of .002 can occur at temperatures in the order of 0°C and with relative humidities in the region of 45% as was recorded on August 13, 1976.

How important is specific humidity? A relative humidity of 45% at 7°C has a corresponding specific humidity of .004. Is this as potentially dangerous as a relative humidity of 45% at 0°C when the specific humidity is in the order of .002 or lower?

ELEVATORS

There are about 200 grain elevators on the Highveld with a total capacity of over 10 million m^3 (230 million bushels). The largest installation has a capacity of 200 000 m^3 (4,7 million bushels) but the average size is about 50 000 m^3 (1,15 million bushels).

These are not large elevators but they are distributed over a wide and representative area. They are generally modern in design. Fig 4 and 5 illustrate typical elevators consisting of 15 m diameter free standing concrete bins with semi-hopper bottoms and reclaim tunnels. The workhouse is normally constructed between four 7,5 m diameter bins and cladded with sheeting. Free standing concrete workhouses have, however, been extensively used. Gantries are now built with grating floors but many of the older elevators have fully enclosed gantries.

The elevators operate mainly from 06h00 to 18h00 and are essentially storage installations i.e. they are seldom filled more than once during a harvesting season.

The mild climate of the Highveld has meant that no attempt is made to exclude cold air so that working spaces are reasonably well ventilated. Reclaim tunnels are equipped with high capacity extraction fans and consequently ambient atmospheric conditions are probably applicable in the workhouse spaces.

Maize and wheat are accepted straight from the combine harvester and while pre-cleaners are now commonly used maize is still stored "dirty" in many elevators and cleaned on reclaim. Wheat has always been cleaned before delivery to the bins.

Dust intensity is a relative concept! We do not know if we have a more serious dust situation than normal or not! We certainly have dust! Intake capacities are relatively low - about 150 t/h per conveyor belt with matched bucket elevators and other machinery. Usually two or three sets of machinery are used providing capacities of from 300 to 450 t/h. An indication of the relative dustiness may be derived from Table 4 which tabulates draw off values, for aspiration systems. These figures indicate present "good practice" but many of the older elevators were built to lower standards.

Conveyor belts are used far more than chain conveyors and to date only steel buckets have been used on bucket elevators, fibre glass are now being considered.

CONCLUSION

Could it be that the relative freedom from explosions which South Africa has enjoyed is more directly related to the design and size of the grain elevators than to climatic factors? We do not know!

We hope that the knowledge that will be pooled at this symposium will help to answer this question and hope that our limited contribution will assist in achieving the overall objective.

TABLE 1: MEAN HOURLY VALUES OF RELATIVE HUMIDITY FOR THE MONTH OF JULY FOR WEATHER STATIONS IN THE GRAIN PRODUCING AREA

	STANDERTON		GERMISTON		BLOEMFONTEIN		MAFEKING	
Hr	RH %	Temp °C	RH %	Temp °C	RH %	Temp °C	RH %	Temp °C
1	65	2,9	61	6,3	62	4,0	66	4,5
2	68	2,2	65	5,8	65	3,5	67	4,1
3	71	1,4	67	5,4	67	3,1	68	3,8
4	73	0,8	68	5,1	68	2,6	69	3,6
5	74	0,2	70	4,7	71	2,1	70	3,3
6	76	-0,2	71	4,5	73	1,8	71	3,2
7	77	-0,6	72	4,5	74	1,4	72	3,1
8	75	1,8	69	6,3	71	3,3	65	6,2
9	65	5,7	58	9,5	58	7,2	49	11,9
10	51	9,9	50	11,6	49	10,2	38	15,2
11	39	13,2	43	13,3	43	12,3	32	17,1
12	30	15,2	38	14,6	38	13,9	30	18,3
13	25	16,5	34	15,5	35	14,9	28	19,2
14	23	17,0	32	16,1	32	15,6	26	19,7
15	22	17,5	32	16,3	31	15,8	26	19,9
16	22	17,1	32	15,9	31	15,6	26	19,7
17	28	15,1	35	14,3	33	14,4	28	18,6
18	35	11,1	40	11,7	40	10,2	36	14,8
19	40	9,3	45	10,2	48	7,8	45	10,9
20	45	8,0	48	9,2	51	6,7	51	8,4
21	49	6,7	50	8,4	55	6,1	55	7,1
22	54	5,4	54	7,8	56	5,7	59	6,3
23	57	4,4	56	7,2	57	5,2	62	5,4
24	60	3,6	59	6,7	59	4,6	65	4,9
Mean	51	7,7	52	9,6	53	7,8	50	10,4

- Climate of South Africa
  Part 1 Climate Statistics,
  Publication WB 19 -
  Weather Bureau Pretoria, 1968

TABLE 2: HOURLY VALUES OF RELATIVE HUMIDITY AND TEMPERATURE FOR SELECTED DRY DAYS - JAN SMUTS AIRPORT, GERMISTON

Hr	June 14 1977		June 25 1977		July 21 1977		Aug 13 1976	
	RH %	Temp °C	RH %	Temp °C	RH %	Temp °C	RH %	Temp °C
1	55	6,6	39	9,4	31	6,5	46	-1,1
2	67	4,0	42	8,6	31	6,5	56	-2,1
3	64	4,9	44	8,8	31	6,4	63	-2,3
4	56	5,4	44	9,4	34	5,8	68	-2,0
5	53	4,8	42	9,9	34	5,9	74	-2,1
6	51	4,5	42	9,8	36	4,7	75	-2,3
7	48	5,4	38	10,1	38	5,5	77	-2,9
8	44	8,4	35	10,3	36	8,2	71	1,5
9	31	12,6	39	12,0	26	13,3	46	5,7
10	26	14,7	35	14,1	22	14,9	34	7,4
11	24	15,7	27	15,3	20	16,3	31	9,2
12	17	17,3	19	16,3	16	18,0	28	10,6
13	13	17,5	15	17,5	11	18,5	25	11,15
14	10	17,7	14	18,2	10	19,2	23	12,7
15	08	17,7	14	18,3	08	19,7	23	13,4
16	07	16,9	13	17,9	08	19,2	20	13,0
17	08	14,7	13	16,9	09	17,7	18	12,3
18	12	11,6	13	15,3	13	16,1	22	9,7
19	16	9,7	15	13,5	15	14,1	26	7,4
20	17	8,8	16	12,8	18	13,6	30	6,8
21	16	10,9	16	12,3	21	12,1	31	6,5
22	15	9,8	18	12,0	22	12,0	34	5,6
23	23	4,7	20	10,9	24	10,8	34	5,6
24	48	4,4	25	9,8	26	10,6	36	5,5
Mean	30	10,3	27	12,9	23	12,3	41	5,4

TABLE 3: AVERAGE MONTHLY 08h00 AND 14h00 RELATIVE HUMIDITIES FOR SELECTED TOWNS

MONTH	PIET RETIEF		BETHAL		POTCHEFSTROOM		HOOPSTAD	
	08h00	14h00	08h00	14h00	08h00	14h00	08h00	14h00
Jan	79	58	77	52	67	38	63	32
Feb	83	57	78	54	74	48	73	44
March	85	54	81	52	80	46	76	42
April	81	49	77	46	75	37	76	40
May	73	38	76	39	74	35	78	36
June	73	36	75	38	72	33	76	34
July	72	33	72	37	68	30	75	34
Aug	70	36	67	37	59	29	67	33
Sept	66	37	64	40	50	26	56	28
Oct	73	48	68	44	56	26	56	31
Nov	73	52	71	47	58	32	54	30
Dec	77	58	72	49	62	36	60	37
Year	75	46	73	45	66	35	67	35
Lat.	27°00'S		26°27'S		26°44'S		27°43'S	
Long	30°48'E		29°28'E		27°04'E		26°46'E	
Altitude	1260 M		1640 M		1352 M		1317 M	
Ave Rainfall	919 mm		754 mm		608 mm		537 mm	

From Climate of South Africa - Part 1.
Climate Statistics, Publication WB 19,
Weather Bureau Pretoria, 1968

TABLE 4: DRAW-OFF VALUES OF ASPIRATION SYSTEMS m^3/min BASED ON 150 t/h UNIT BELT CAPACITY

	m^3/min
Reclaim conveyor	35
Road intake conveyor	35
Elevator boots	9
Feeder to overbin belt conveyor	11
Chute aspiration (pre-feed)	14
Final cleaner	130

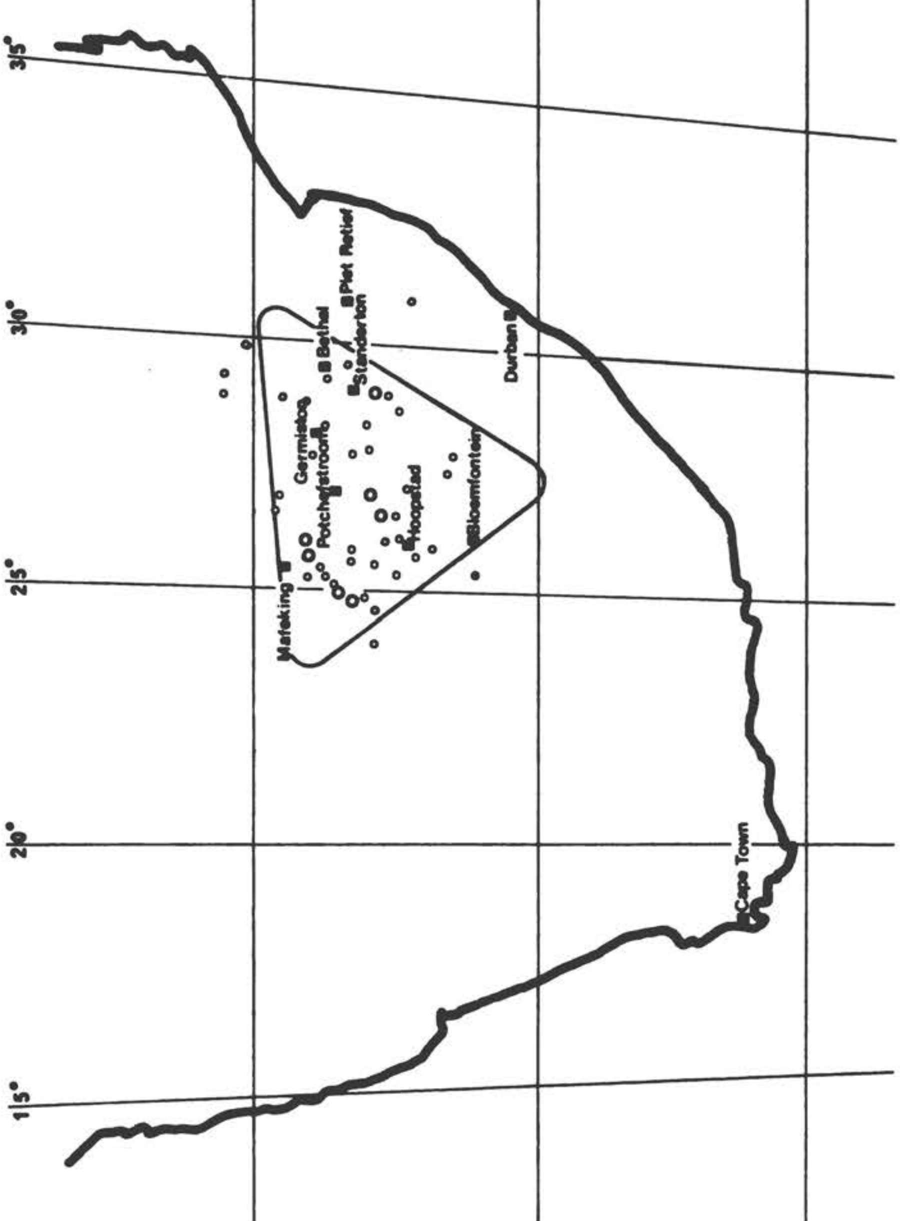

Fig 1. - Distribution of major grain storage installations

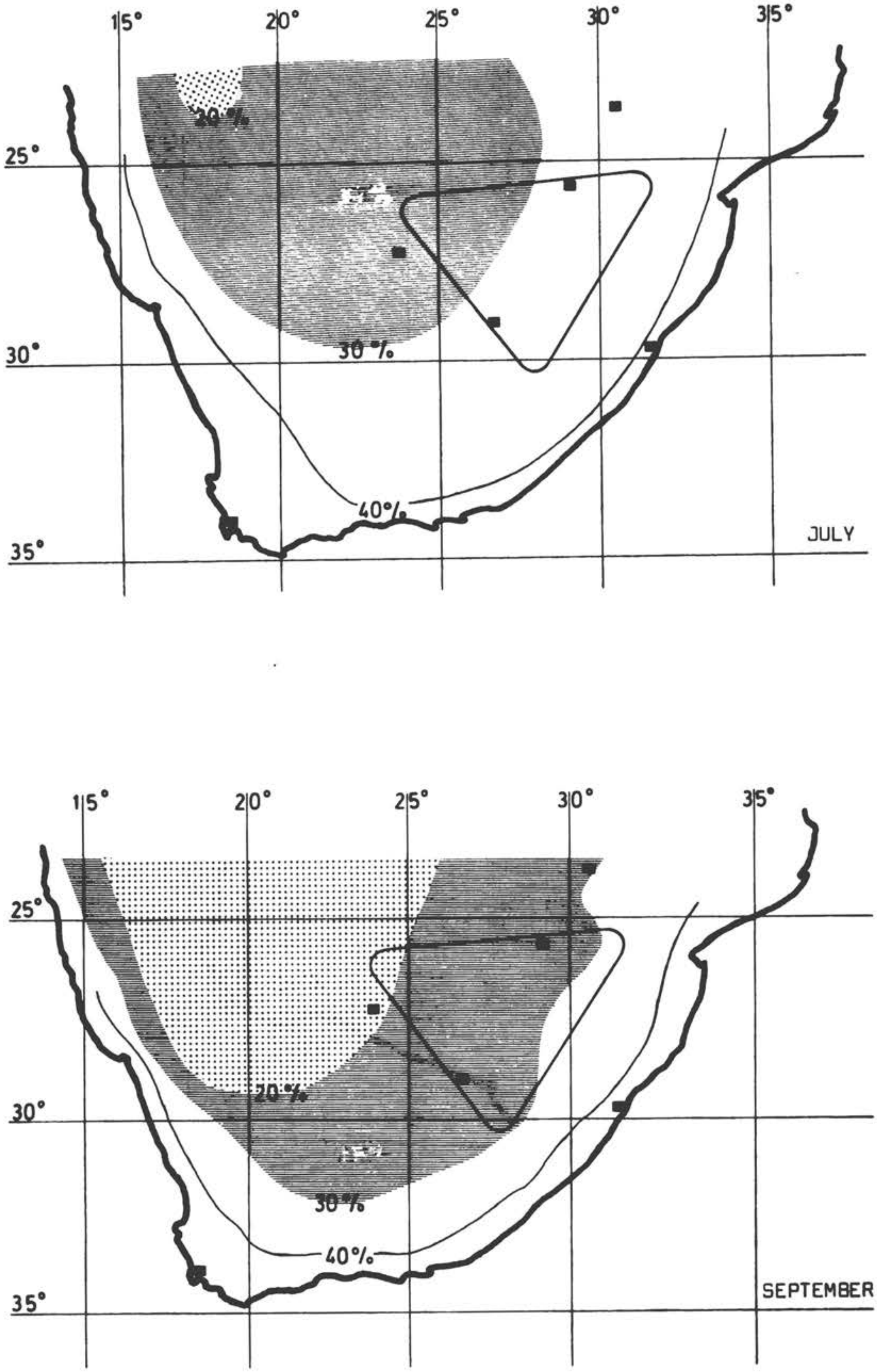

FIG 2 MEAN MONTHLY RELATIVE HUMIDITY ZONES AT 14h00 - JULY AND SEPTEMBER

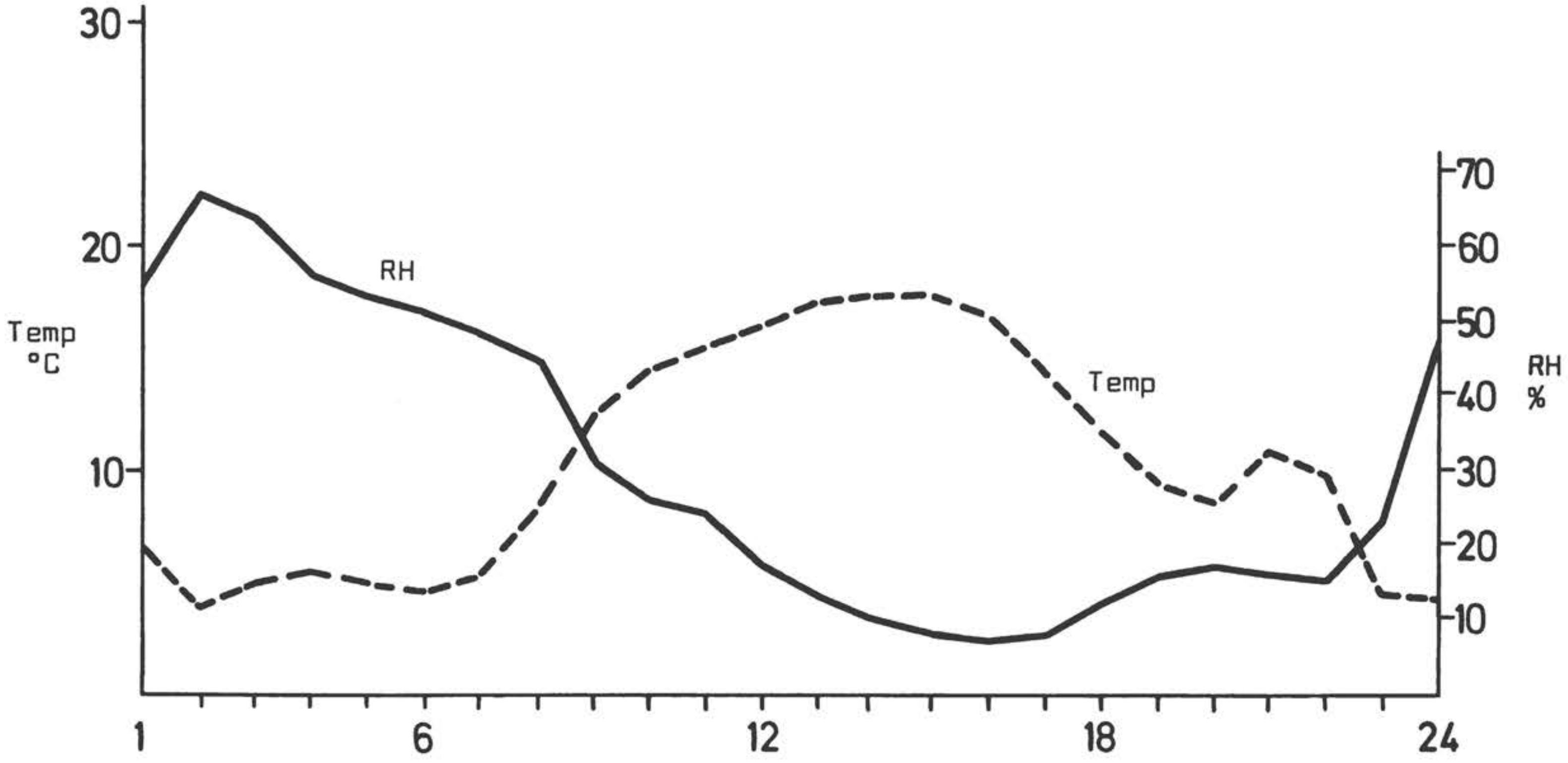

Fig 3: TYPICAL DIURNAL VARIATION IN RELATIVE HUMIDITY AND TEMPERATURE

FIG 4: TYPICAL ELEVATOR - 37 000 m^3

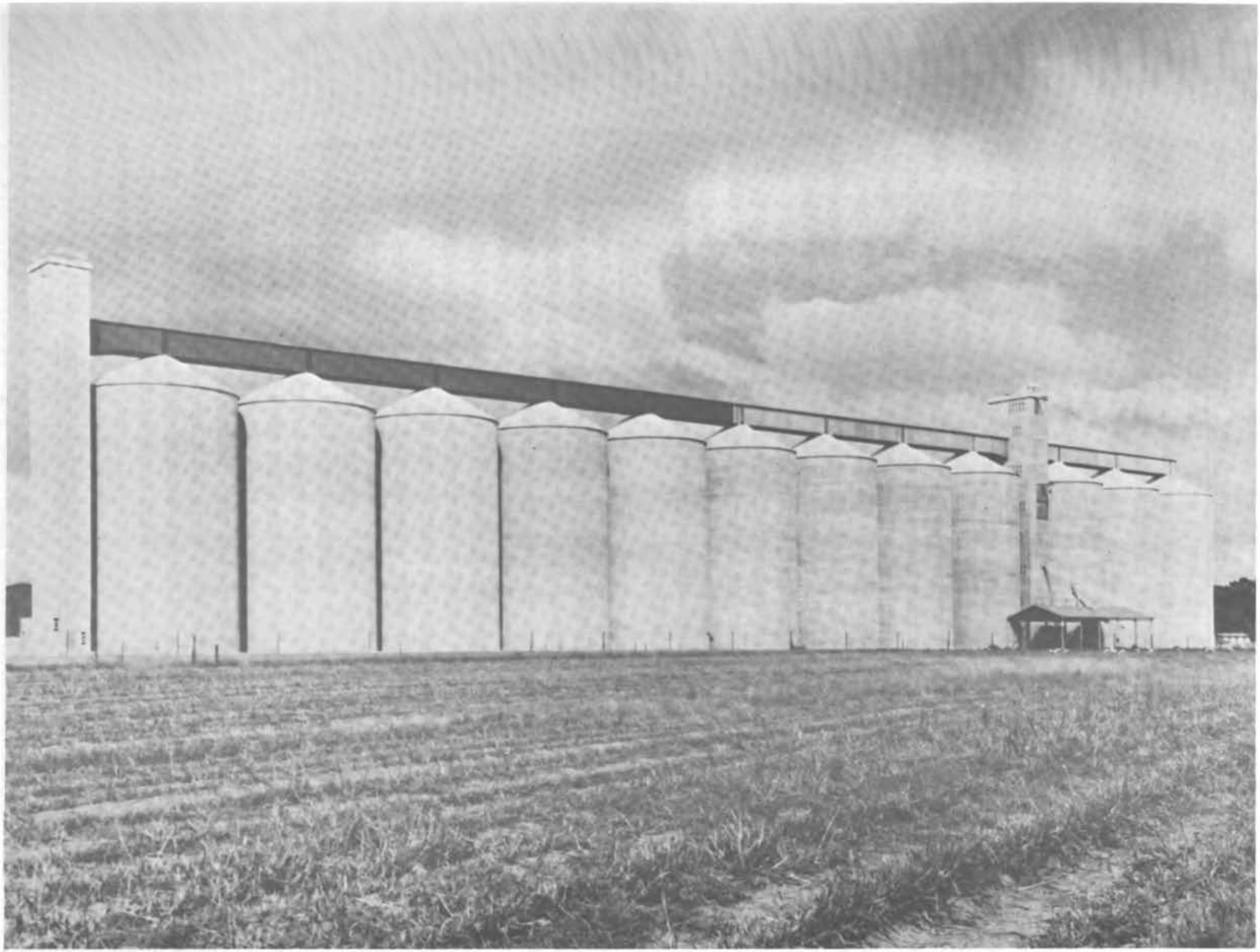

FIG 5: TYPICAL ELEVATOR 59 000 m^3

IGNITIONS DUE TO ELECTROSTATICS IN POWDER SYSTEMS

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1. INTRODUCTION

It is well known that ignitions can occur in powder storage systems by means of electrostatic sparks. In some cases the precise source of the spark can be easily identified and eliminated, in others the cause is less certain and is just written off in general terms as 'electrostatics'.

The fundamental mechanism by which charge builds up as powder moves against the surfaces of the plant is not well understood. There is no way that the quantity of charge transferred or even its polarity can be predicted theoretically and there is no standard laboratory test which adequately simulates behaviour in industrial plant. Although many explosions which do occur could be prevented with current knowledge, there are still large gaps in our knowledge.

To aid this problem a group of 11 companies including food, pharmaceutical and petrochemical industries from several different countries including the U.S.A., have joined together with the British Health and Safety Executive to sponsor a research programme at Southampton University. A full scale pneumatic transport and storage system is being built which is fully instrumented and will be designed so that electrostatic ignition sources can be identified in the silo. The silo is 4m diameter and pumping speeds and conditions are representative of a wide range of industrial applications.

In this paper an analysis of fundamental ignition mechanisms will be presented with particular reference to our experience with industrial installations. Results of some laboratory tests on charging of powders will be briefly discussed and the full scale test facility being set up at Southampton will be described. Much of the work which we are allowed to publish freely has been carried out on chocolate crumb but results are applicable to many other food materials including grain products.

2. MECHANISMS OF ELECTROSTATIC IGNITION

2.1 Isolated conductors

When any two dissimilar materials come into contact charge is transferred across the boundary. If both materials are conducting and connected to earth the charge immediately flows away but if either in insulating or an isolated conductor, charge can build up until the electric field reaches the level where air breaks down producing a spark. Insulator surfaces can hold a maximum charge $\sim 3.10^{-5}C/m^2$. Only a small area tends to break down at any time and therefore sparks from insulator surfaces are usually of very low energy and cannot ignite a powder. However, isolated conductors (e.g. metal buckets on insulating webs, trolleys on rubber wheels, personnel in insulating footwear) can store considerable charge which can be released instantly giving sparks many times more energetic than the minimum ignition energy of a dust cloud. Belt and bucket conveyor lines commonly run on insulated belts and rely on the conductivity of the powder to make the connection between the buckets and to earth. In many cases, in the grain industry, the powder is sufficiently conducting for this to be so but with a more insulating powder, perhaps an extremely dry one, the connection will be lost and static can build up. In general terms all isolated metal should be strapped to earth or if the powder itself is being relied on to provide the conducting path, a field meter should be fitted at some point to check that the potential never rises above a few hundred volts.

2.2 Plastics

For some time it was assumed that plastic surfaces could never give a large enough spark to ignite a powder, but it has now been shown that highly charged plastic can produce 'Lichtenberg discharges' which can be highly energetic. This occurs if the plastic is backed by metal during charging. The metal backing increases the capacitance of the system allowing a much higher charge to be stored on the plastic surface for the same breakdown potential. At these high charge levels the spark discharge spreads across a large surface area releasing considerable energy. In one industrial explosion investigated by the Wolfson Unit at Southampton the source of the ignition was found to be a length of PVC pipe inserted up inside the silo for bottom loading as shown in Fig. 3. The pipe was wrapped with wire in an attempt to reduce static but in fact this increased the capacitance of the system enabling sufficient charge to be stored on the inside surface of the pipe for a Lichtenberg type discharge to occur so the silo containing chocolate crumb exploded. The problem was accentuated because the silo was bottom loading with an internal pipe. Charged conducting powder built up on the outside of the pipe in a 2cm thick layer. There was therefore a high electric field across the pipe wall itself and continuous corona discharging could be seen and heard both inside and outside the pipe. In this particular case a simulation rig consisting of a road tanker was set up and was found to ignite whenever a PVC pipe was used in this way.

2.3 Charged powder

When powder flows in an earthed metal pipe no charge is retained on the pipe but charge can build up on the powder if the rate at which charge is produced by rubbing exceeds the rate at which it decays by conduction. The production rate cannot be predicted but the decay time constant is approximately given by $\tau = \varepsilon\varepsilon_0\rho$ where ρ is the resistivity of the powder, ε its dielectric constant and ε_0 the permittivity of free space.

A metal powder such as aluminium has a resistivity of $10^8\Omega$ and a dielectric constant $\sim$100 hence the charge decay time is $\sim$.1 sec. Although charge will decay in less than 1 second when the powder is stationary in contact with earth, it is very possible for the charging rate to exceed the decay rate when the powder is moving at speed. It certainly cannot be assumed that a conducting powder in an earthed pipe is necessarily safe. A grain product might be expected to have a resistivity of between 10^7 and $10^{10}\Omega$m (depending on its water content) and a dielectric constant $\sim$10. Fig. 1 shows the charge levels produced on the powder in a laboratory by chocolate crumb impacting against a metal surface. The apparatus in which this test was carried out (shown in Fig. 4) was designed to maximise charging and in fact produced levels close to the theoretical maximum. Charging would not be expected to be as efficient in an industrial set-up but results do underline the fallacy in the belief that a conducting powder will not charge in an earthed metal system. When charged powder reaches the silo or storage vessel, the coarse particles quickly settle out and the fines form a cloud in which the individual particles are isolated by the air. It is possible that, providing the mean field exceeds 5kV/cm, the charged cloud of powder could release sufficient energy for an incendive spark by means of a lightning type discharge analogous to a thunderstorm situation. Boschung, Hilgner, Luttgens, Maurer and Widner (1977) working for Ciba Geigy in Switzerland believe that a lightning discharge will not occur in a chamber of less than 3m diameter. This is based on the fact that no ignition was obtained in 50 runs producing highly charged powder clouds in the test chamber. The field exceeded the minimum level and the correct explosive density of powder was present. However, there are still ignitions occurring in industry for which no source can be identified and the possibility of sparks from the powder itself must be investigated further. It is also possible that sparks could occur from the charged stream of powder emitted into the silo back to the inlet pipe. In this region the powder cloud is dense and the electric field is likely to be high.

As a conducting powder settles charge can leak to earth within a few seconds. An insulating powder such as some of the antibiotics or a polymer will need several hours or even days for the charge to leak away. In this case, as the powder settles the charge density builds up to such an extent that the air breaks down and the powder discharges by tiny sparks. The light from this effect can be seen with an image intensifier. Fig. 2 shows a surface in which a few layers of frictionally charged polymer powder have settled, viewed with an image intensifier. These tiny discharges are normally non-incendive but the possibility that a more energetic process could occur or that they heat the powder cannot be ignored. The effect of the free ions which will be created by the process is also not known.

The whole question of ignitions from the charged powder itself both in a cloud and in the bulk requires further investigation.

3. LABORATORY TESTS ON POWDER CHARGING

Numerous laboratories have carried out tests to try to simulate the charging behaviour of powder in full scale systems. So far no satisfactory technique has been found. The amount of charge, the ranking of the powders and even the polarity all change according to the test used. However, one or two interesting points do emerge.

At Southampton tests have been carried out using a fan type of charger which reproduces both rubbing and impact contact between powder and metal. Tests have also been carried out feeding powder through straight tubes. Enstad 1978.
The fan device (shown in Fig. 4) gave chocolate crumb a net negative charge but it was found that this was made up of a large weight of large particles (between 200μ and a few mm) with a net negative charge and a much smaller weight of fines with a high positive charge (Fig. 5). This was not found when the material was tested by flowing through straight pipes ½ inch in diameter but it has been observed in storage silos. Fig. 6 shows the electric field measured in a silo being filled with pulses of a polymer powder by means of a pneumatic transport system. A negative field was measured during the flow of the powder but between pulses the field was positive as the fines took longer to settle. This phenomenon means that it is possible to get strong charge separation by gravity in a silo. Enstad working at the Christian Michelsen Institute in Norway has found a polarity change with PVC passed through a straight 1" pipe as the pipe becomes coated. He attributes the effect to the difference between powder/powder contacts and powder/pipe contacts.

However, work at Southampton indicates that powder velocity and the difference between rubbing and impacting contacts may also be important.

4. SOUTHAMPTON UNIVERSITY PROJECT TO STUDY HAZARDS IN POWDER STORAGE SYSTEMS

It can be seen that there are a large number of unanswered questions concerning electrostatics and industrial transport of powders. It is extremely difficult to solve the problems working on production systems which are usually only available for short periods of time and are not designed for the purpose. For this reason an industrial scale experimental silo system is being set up at Southampton. A flow diagram of the system is shown in Fig. 7. Powder can be fed from either silo by means of a variable speed rotary blow through valve. A Rootes type blower (also of variable speed conveys the powder at velocities up to 30m/sec. The silos are of a standard design except that the filters and other accessories are sited in a periphery chamber leaving the maximum possible roof area free for venting. Tests will therefore be able to be carried out which lead to ignitions, in complete safety. A Nitrogen inerting system is fitted to ensure that ignitions only occur when expected. The filter is a bag type device and air is recirculated through a humidity controller so that the effect of relative humidity can be tested. There is a long horizontal section of pipe in which extra bends, transparent sections, or different pipe materials can be inserted. The complete system is fully instrumented to measure electrical and flow conditions. It has been designed to incorporate the maximum flexibility so other feed mechanisms and conditions could be tested at a later date. The aim of the work is to investigate fundamental ignition mechanisms particularly those involving the powder itself, to develop instrumentation for early detection of hazardous conditions and to design fail safe methods of static elimination. At present, static elimination in silo systems is at a very early stage of development. Passive elimination which is basically earthed pointed rods inserted into the powder flow have been tested by Southampton in an industrial silo. An order of magnitude decrease in charge was found when a passive device was fitted to an industrial silo. Active dischargers powered by a high voltage source are more efficient but devices must be developed which are completely fail safe and which cannot themselves present a hazard. A laboratory study will be carried on in parallel with the site work at Southampton to try to find a system which adequately simulates the behaviour observed in the main system. An attempt will be made to devise a standard laboratory test which will enable powders to be classified according to their electrostatic behaviour. The silo system will provide a very useful experimental facility which will be available to industry through the normal channels of the Wolfson Advisory Unit for tests on any aspect of powder transport and storage.

REFERENCES

P. Boschung, W. Hilgner, G. Luttgens, B. Maurer and A. Widner J. Electrostatics 3 1977 303 - 310.

G.G. Enstad (Chr. Michelsen Inst. Norway) Presentation for EF ChE Working Party on Static Electricity Southampton April 1978.

Fig. 1 Plots of Charge to Mass Ratio versus the Powder Velocity for Metal and Plastic Tribo-System

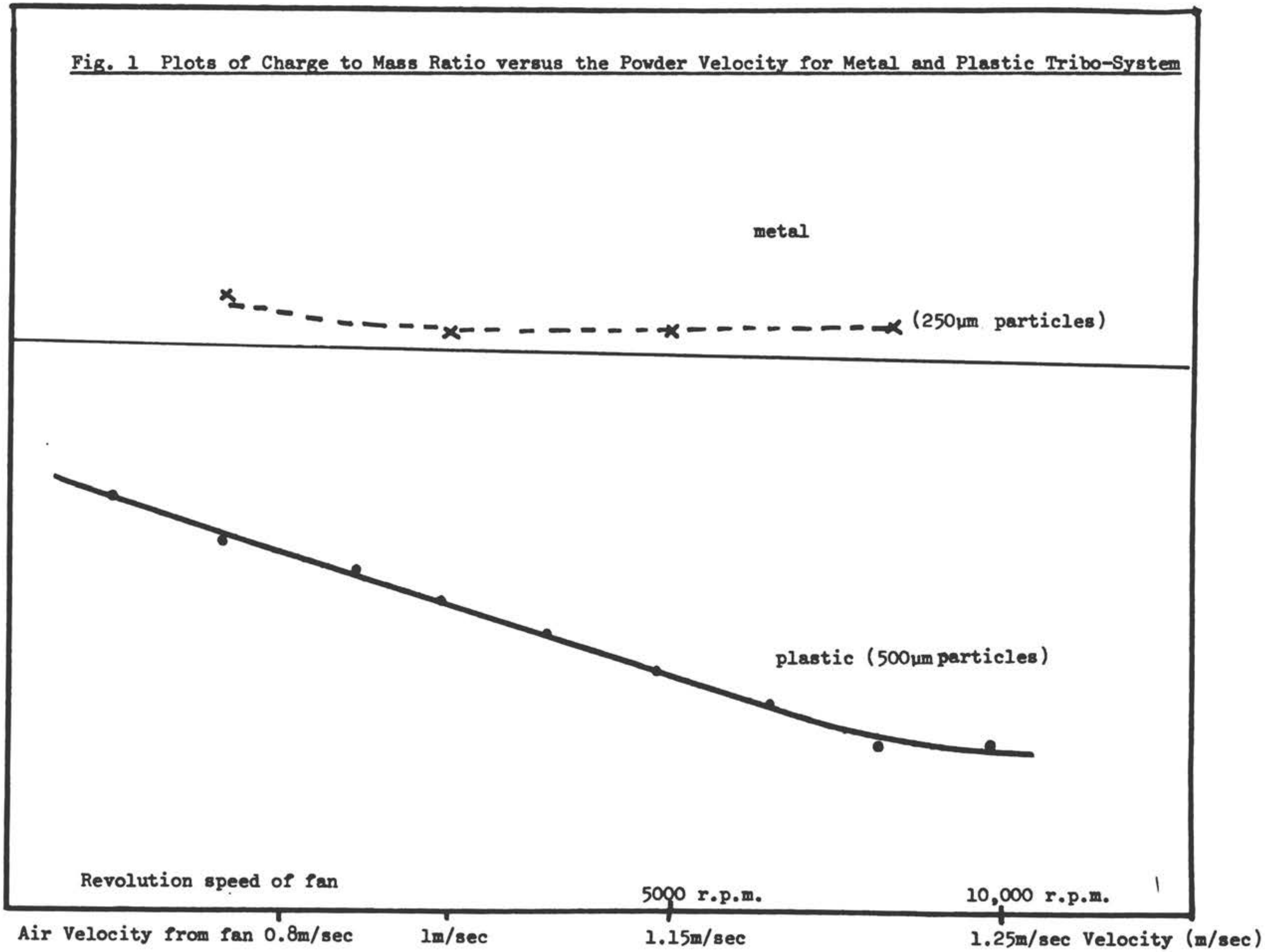

Fig. 2 Photograph of image intensifier view of Polymer Powder settling on an earthed plate

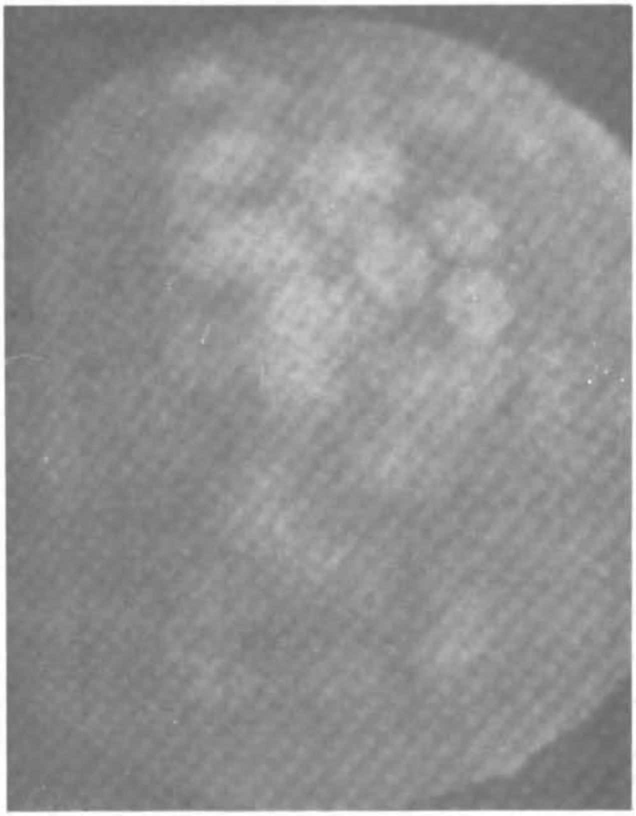

Fig. 3 Schematic View of chocolate crumb silo in which ignition occurred

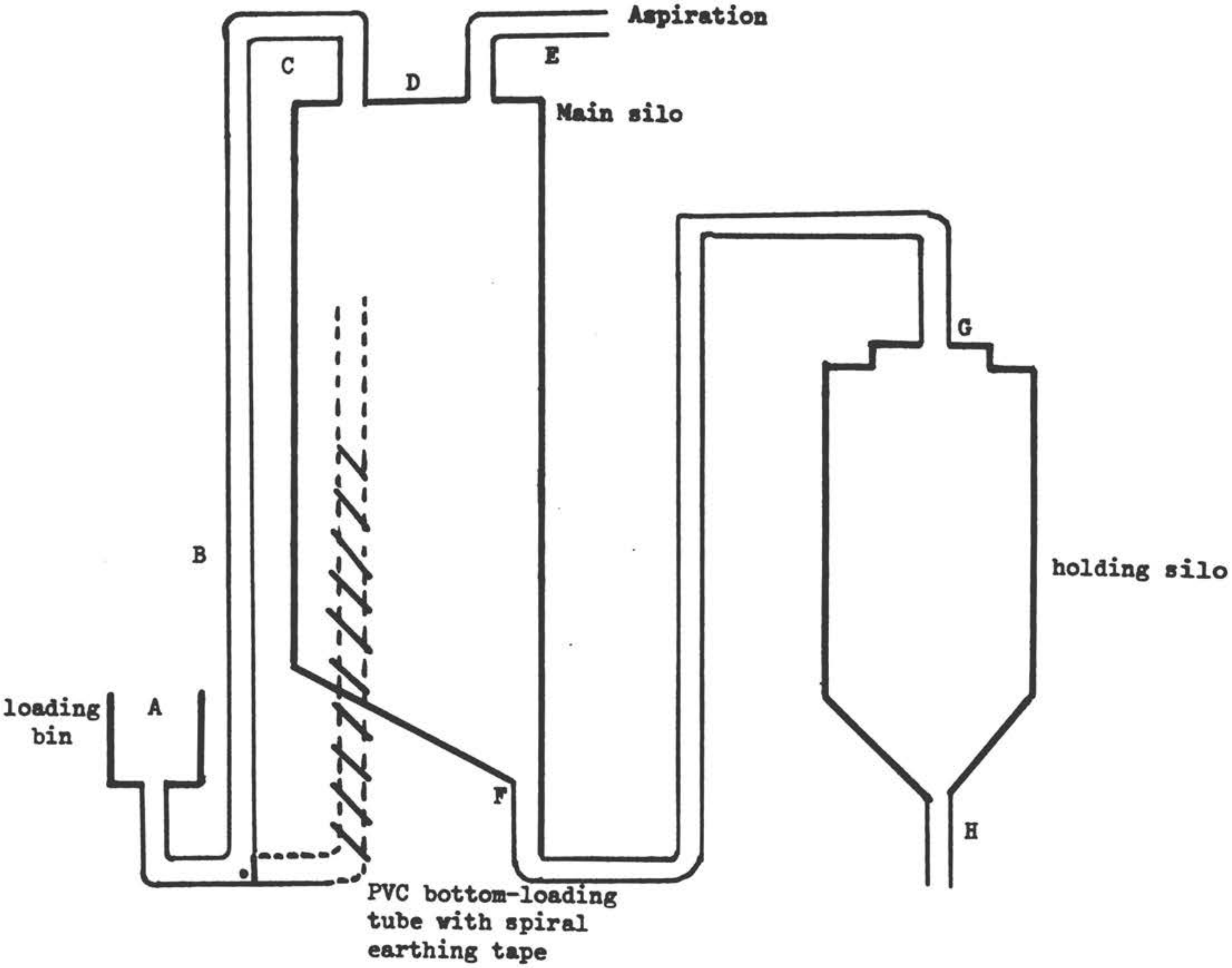

Fig. 4 Schematic Presentation of Assembly used for Charging Powder

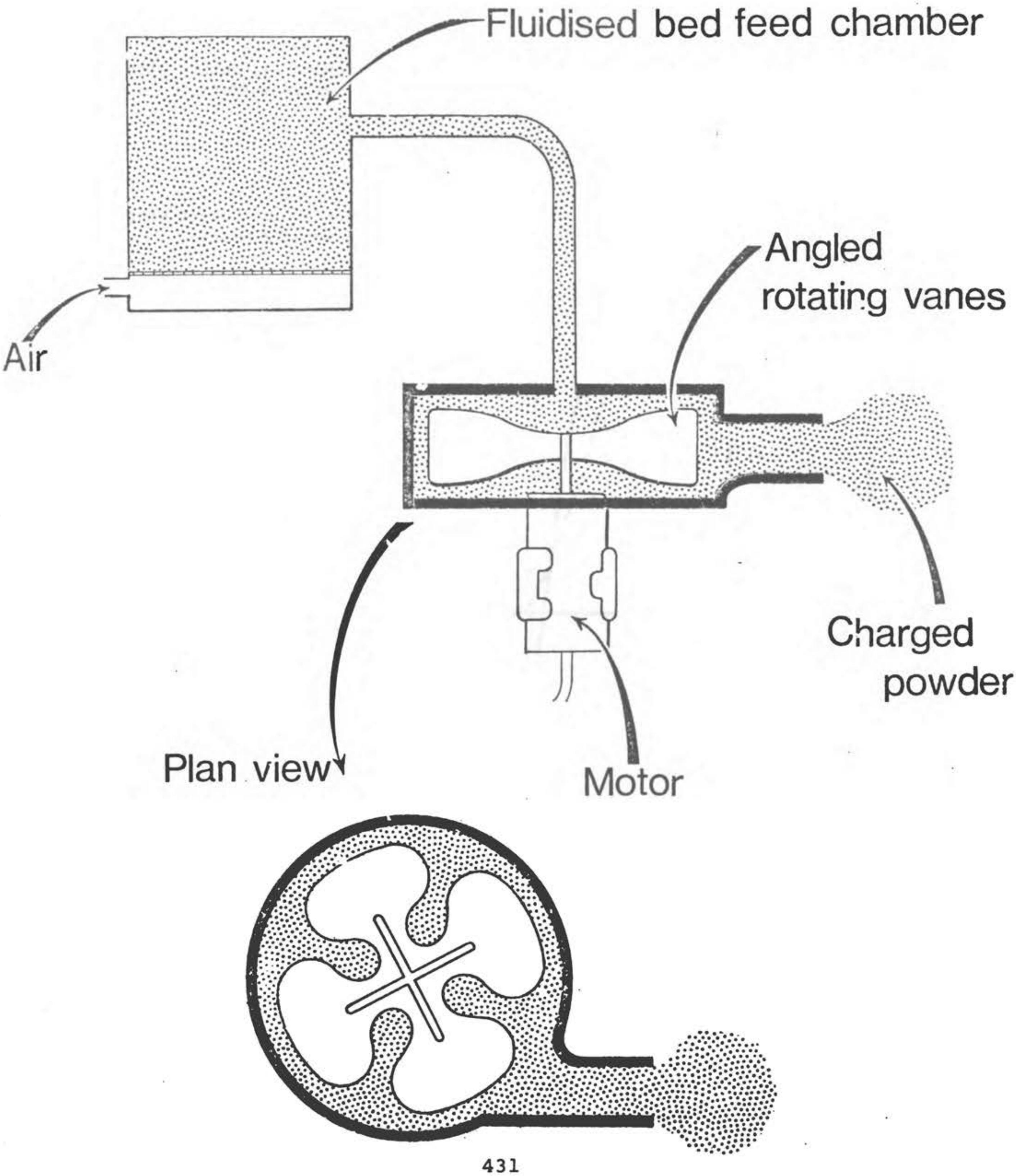

Fig. 5 Charge to Mass Ratio versus Particle size of a Food Product, illustrating the Bipolar Nature of the Material

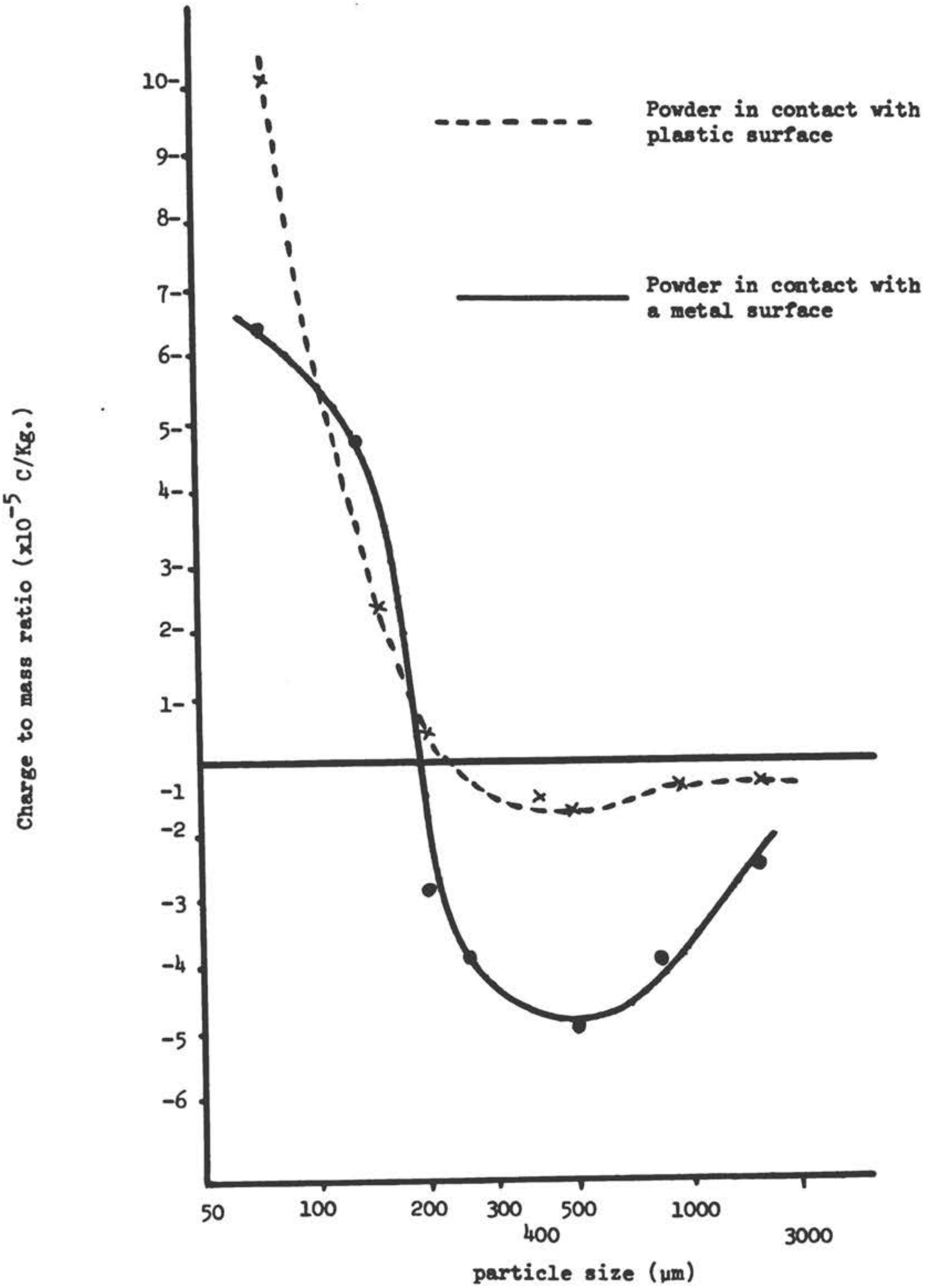

Fig. 6 Electric field measured in a Powder Silo during Pulsed Feeding

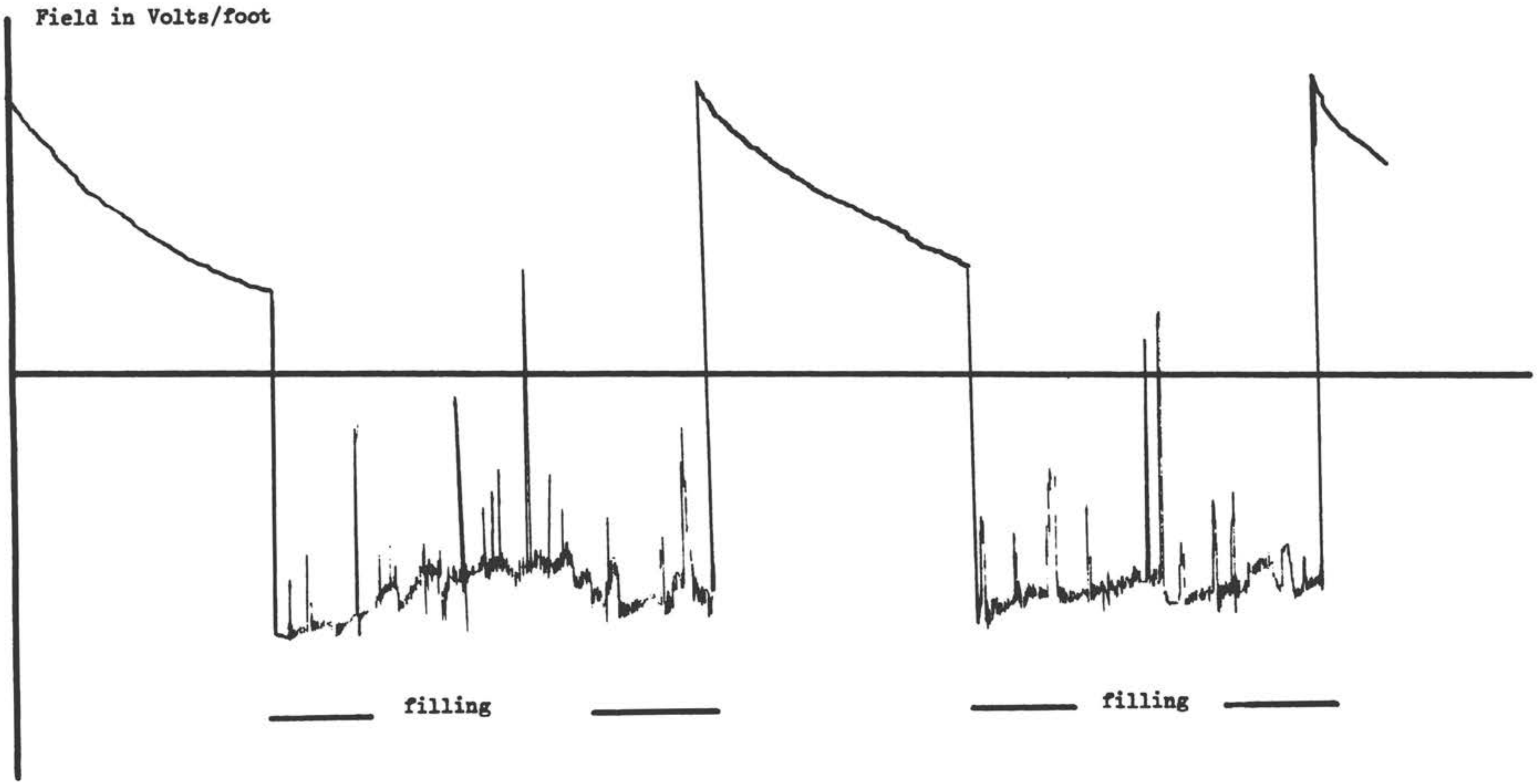

FIG. 7. Schematic view of experimental System at Southampton.