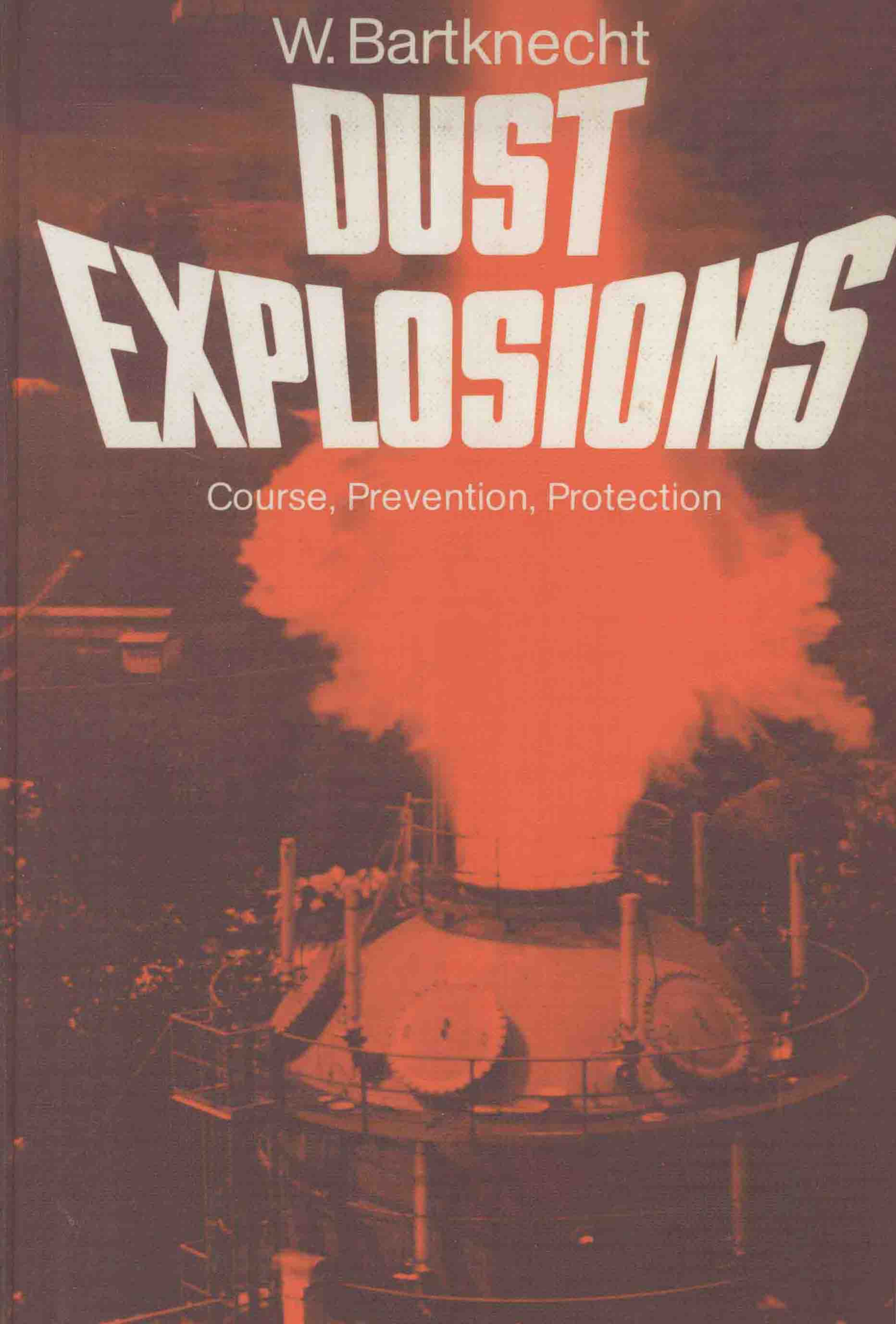
W. Bartknecht

DUST EXPLOSIONS

Course, Prevention, Protection



Wolfgang Bartknecht

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With a Contribution from Günther Zwahlen

With a Preface by H. Brauer

Translation from German by
R. E. Bruderer, G. N. Kirby, and R. Siwek

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Preface

Dust represents the most hazardous form of solid matter. It may result from natural or technical processes. Dust must be considered as a phase of its own with very specific characteristics. Dust is defined as fine particles of a solid dispersed in a gas. In considering explosions, the gas will initially be thought of as air with its usual oxygen content. In an explosion the dusty solid will always spontaneously oxidize.

The violence of an explosive oxidation increases with increased fineness of the individual solid particle because each particle's surface area increases quite rapidly in comparison with the total volume of the solid dispersed in the gas. An example may illustrate this statement. Consider a solid with an initial volume assumed to be 1 cm^3. If it exists in the form of a cube then its surface area will be 6 cm^2. However, if the same volume is visualized as particles with a 1 μ diameter, then the total surface area will be $6 \cdot 10^4$ cm^2. The surface of the dust is therefore ten thousand times larger than the reference cube. The actual effective conditions may even reach much larger ratios as with decreasing particle size the inner surface area which effects the oxidation process will generally be a multiple of the external surface area. It is the surface of the dust which makes the dust become such a hazardous material.

From a strictly scientific point of view, the course of an explosive oxidation process has so far only been investigated to a rudimentary degree. A satisfactory insight into dust explosions is therefore only possible from comprehensive experimental tests. Due to the high cost of suchtests, it is necessary to analyze the results with great care and to summarize the data with the help of empirical characteristic parameters. These empirical parameters are the basis for the guidelines which have been developed in order to help prevent explosions or at least to limit the consequences.

The author has summarized today's knowledge of the cause, course and consequences of dust explosions in an outstanding fashion. Explosions became the problem around which his professional life developed with great success. Whoever is confronted with dusts, be it the field engineer or the scientist, will benefit from this book and increase the safety of the facility for which he is responsible.

Heinz Brauer
Full Professor of Reaction Technology
Technical University Berlin

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1 Introduction

In past years, the causes of dust explosions have been systematically researched by laboratory-testing the combustion, ignition, and explosion behavior of combustible dust. Step by step, the results and the experience gained have been transferred to industrial practice. Yet, dust explosions still occur, causing major damage and sometimes fatalities. The "Berufsgenossenschaftliche Institut für Arbeitssicherheit" in Bonn [1] lists 357 dust explosions which occurred from 1976–1980 in the Federal Republic of Germany, but only 155 of these cases had been officially reported. In contrast, the "Verband der Sachversicherer" (VDS) (organization of insurance carriers) states 300 cases per year with damage exceeding 50,000 DM each.

In conjunction with the above-mentioned laboratory tests, large, practice-related, full-scale tests were carried out with combustible dusts. The purpose was to develop preventive measures and to test design measures which may not avert an explosion but should limit its dangerous results to an acceptable level. The experience gained over the past years by applying such measures in facilities which process and convey combustible dusts indicates that damage to equipment and personnel can definitely be prevented.

The aim of this publication is to assist people dealing with industrial applications. It reflects the present state of the art and current knowledge of the course of a dust explosion, including the inherent danger of a dust layer.

2 Historical Review

2.1 Occurrence of Dust Explosions

Dust explosions have been known for approximately 200 years,ever since the wind mill was introduced in 1752–1756 for the purpose of grinding cereal grains.

The first explosion which was recognized as a dust explosion occurred in Italy on December 14, 1785. It was reported by the Turin Academy of Science as a flour dust explosion in a warehouse in Turin.

Five additional explosions creating considerable excitement occurred over the next 100 years.

Table 1. Dust explosions

Year	Location	Installation	Dust type	Damage
1785	Turin (Italy)	Warehouse	Flour	Warehouse destroyed
1858	Stettin (Poland)	Roller mill	Grain	Mill building destroyed
1860	Milwaukee (USA)	Mill	Flour	Mill building destroyed
1864	Mascoutah (USA)	Mill	Flour	Mill building destroyed
1869	unknown (Germany)	Mill	Pea flour	Local damage to mill
1887	Hameln (Germany)	Silo	Grain	Silo and building destroyed

In 1887, a grain dust explosion destroyed a silo of the "new Wesermühle" in Hameln, Germany (Table 1). The journal of the "Verein Deutscher Ingenieure" of November 1887 described the explosion as follows: "This accident is unique on the continent. Until now, we had no idea of the enormous destructive effects of such forces."

With increasing industrialization and the change from smaller facilities to large industrial complexes, the frequency of dust explosions has increased since 1887.

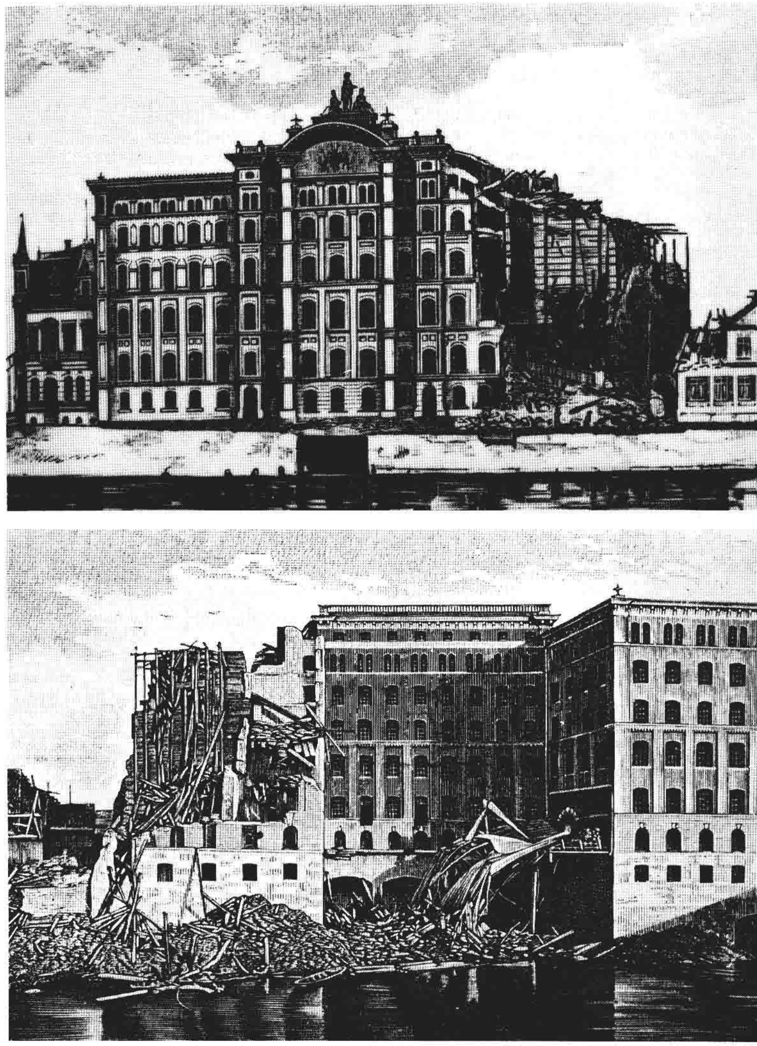
a
b

Fig. 1 a/b. The "Neue Wesermühle" in Hameln, Germany after the explosion in 1887

Most early dust explosions occurred in places where production and dust generation were high due to size and productivity. Up to 1922, the USA and Canada experienced 217 dust explosions. These involved organic dusts from mills, elevators, and silos, starch plants and refineries, as well as plants processing aluminum, chocolate, paper, rubber, seasoning, etc. The multitude of installations affected by dust explosions is striking.

A more recent USA statistic for the time period 1900–1952 lists the dust types involved in 769 explosions (Table 2). The total damage amounted to 88 million dollars and involved 464 casualties and 1229 injured.

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Table 2. Type of dusts involved in dust explosions in the USA (1900–1952)

%	Number of explosions	Type of dust
24.8	191	Grain
16.8	129	Wood
14.7	113	Feedstuff
13.1	101	Flour
5.6	43	Starch
4.8	37	Cork
3.4	26	Sugar
3.3	25	Plastics
3.1	24	Sulfur
3.1	24	Malt
1.8	14	Bark
5.5	42	Miscellaneous
100	769	

But not only the industrial establishment experienced dust explosions. The Pacific Northwest (USA) registered 300 dust explosions in combines during harvest with damages exceeding 1 million dollars.

Statistical information on dust explosions in Germany is scarce for that time period. Nevertheless, 66 sugar dust explosions were reported for the time period 1890–1922, with moderate to catastrophic results. One of the worst explosions occurred on March 16, 1917 in Frankenthal, killing 6 operators and causing considerable damage (Fig. 2).

Other branches of industry experienced dust explosions during the same time period. 77 incidents were registered involving coal dust, dyestuffs, soot, and aluminum. Coal dust explosions alone left 404 dead and 275 injured.

Approximately 30 years ago, one of the most comprehensive books on dust explosions was published by W. H. Geck [3]. The author, who lost his own business due to a wood dust explosion with subsequent fire and who survived a severe sugar dust explosion, described 116 dust explosions in various major industries. The probable causes and effects are analyzed based on his own observations and over 30 years of experience as a consultant (Fig. 3).

In his work he reaches the remarkable and still valid conclusion that every dust may behave differently in different plants due to the influence of innumerable factors unique to each industrial environment.

The years 1976–1978 saw numerous grain dust explosions in silos in the USA. The incidents caused extensive damage and resulted in numerous fatalities and in-

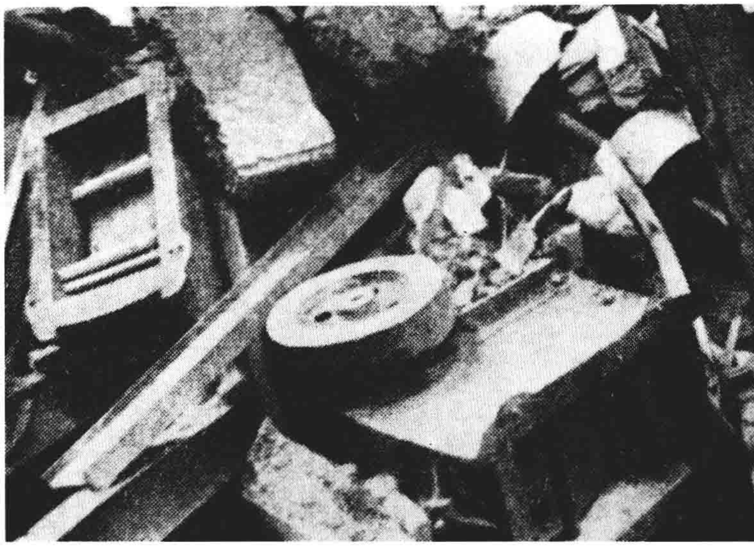

Fig. 2. Effects of a sugar dust explosion [3]

Fig. 3. Wood dust explosion in a furniture factory with subsequent fire [3]

juries. Many symposia dealt with and are still dealing with the causes of these dust explosions. The discussions have concentrated on the effectiveness of preventive measures and other design measures to reduce the consequences of such mishaps to a minimum.

Nowadays, dust explosions are – in the true sense of the word – commonplace in the Federal Republic of Germany, although only a fraction are recorded, as men-

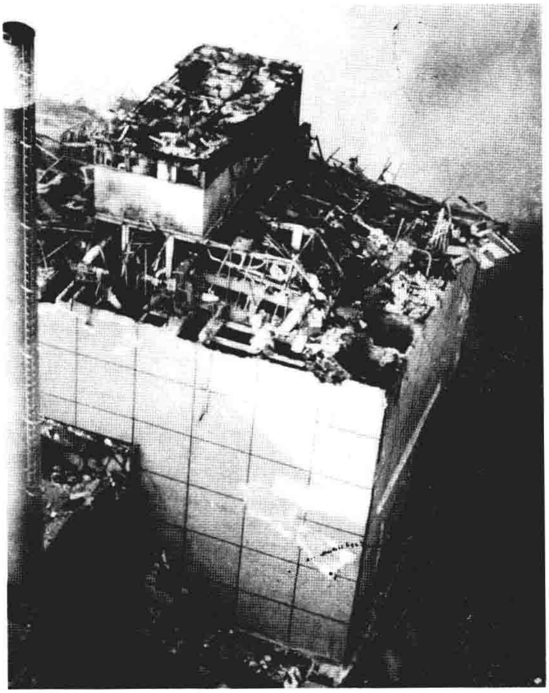

Fig. 4. "Bremer Roland Mill" after a flour dust explosion, 1979

tioned earlier [1]. But not all the mishaps have such a terrible outcome as the 1979 flour dust explosion in the "Bremer Roland Mill" (Fig. 4) which left 14 dead, 17 injured, and property damage of 100 million DM.

357 dust explosions have been analyzed and the frequency of involvement of the various dust categories tabulated (Fig. 5).

Almost one-third of the explosions were caused by wood dusts and every fourth explosion happened in the food and feedstuff industry. These figures are practically identical with the ones recorded in the USA for the time period 1900–1952 (Table 2).

In Germany, as well as in the USA, most of the dust explosions occurred in the industries cited above. The percentages given in Fig. 5 are therefore representative of both countries.

Figure 6 shows the percentage of equipment categories involved in the dust explosions. Every fifth of these happened in a silo or bunker. Such silo explosions are often spectacular, especially if an entire cluster of silos is involved (Fig. 7). Grinding and conveying systems, as well as dust collectors, participate at almost the same ratio.

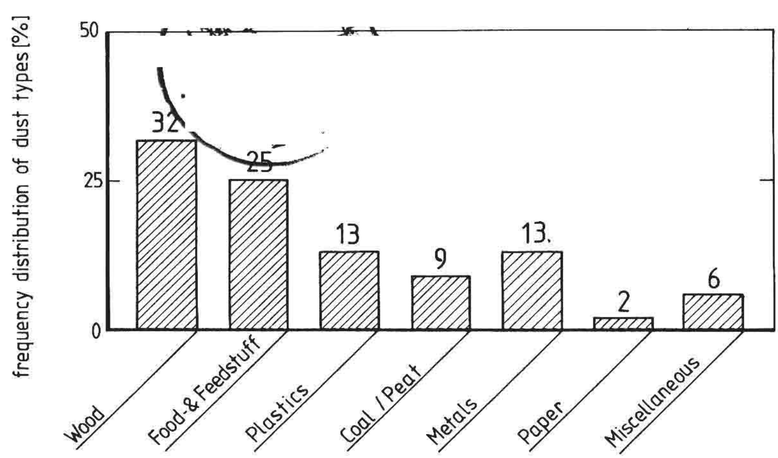

Fig. 5. Frequency distribution of dust types involved in 357 dust explosions [1] (1965–1980)

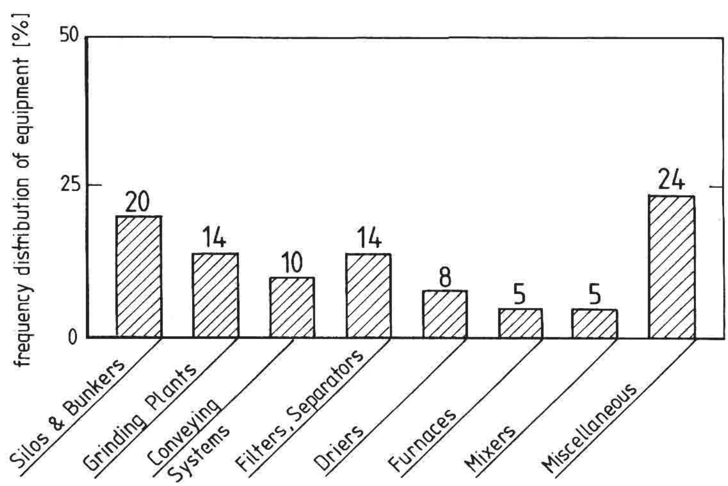

Fig. 6. Frequency distribution of types of equipment involved in 357 dust explosions [1] (1965–1980)

In conclusion, Fig. 8 represents the frequency distribution of the various ignition sources responsible for the above dust explosions. Although it is sometimes very difficult to determine the actual ignition source, it is apparent that mechanically produced sparks present the most frequent source in industrial practice, with 29 %. This includes sparks generated through friction, grinding, and impact. Therefore, it is not surprising that present research is concentrated on the effectiveness

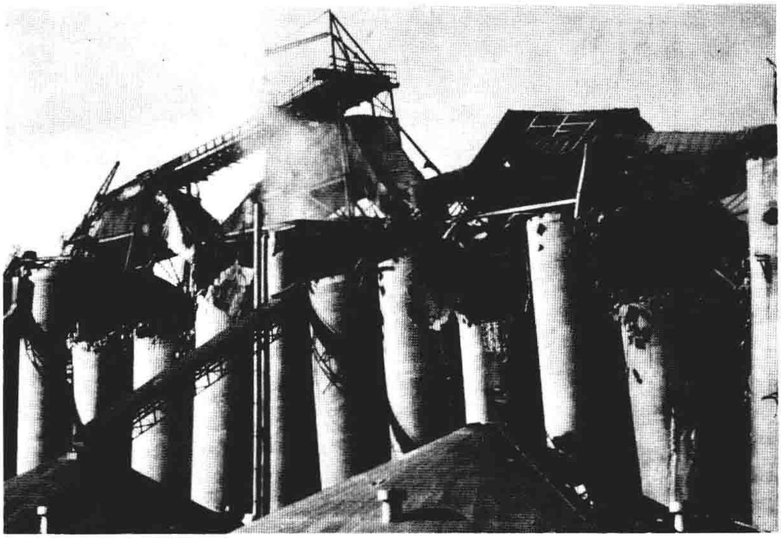

Fig. 7. Effects of a grain dust explosion in a group of silos

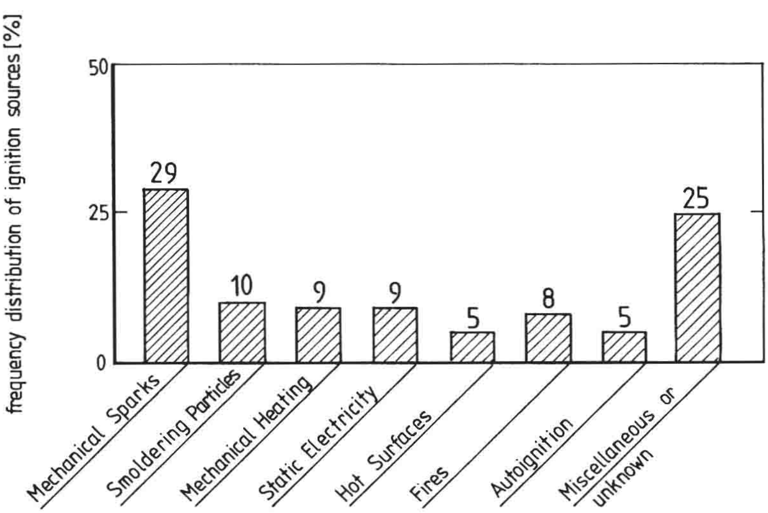

Fig. 8. Frequency distribution of ignition sources responsible for 357 dust explosions (1965–1980)

of such sources in the case of dust/air mixtures. All other sources combined participate practically with the same probability as mechanical sparks. The outlined case-histories, which are certainly not complete, may serve as an overview of the dangers which have been known to exist for the past 200 years in processing or handling combustible dusts. The often-voiced opinion that a plant which processes dusts

Fig. 9. Educational poster based on a design of US Departments of Agriculture and Interior

is safe because it has not experienced an explosion in the past years or decades has been frequently disproven in practice.

The fact that about 36% of all explosions have been caused by human error, i.e., thoughtlessness, negligence, indifference, and ignorance shows clearly that effective instructions and training of employees are essential.

In this context, the poster designed by the US Departments of Agriculture and Interior at the turn of the century is still valid with its slogan: "Watch out for dust explosions. You may lose property and life, bread and work".

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