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Historical Trends in the Occurrence of Fires and Explosions in the U.S. Pulverized Coal Fired Utility Industry

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HISTORICAL TRENDS IN THE OCCURRENCE OF FIRES AND EXPLOSIONS IN THE U.S. PULVERIZED COAL FIRED UTILITY INDUSTRY

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ABSTRACT

Under an Electric Power Research Institute (EPRI) program, surveys and data analysis were conducted to determine the fire and explosion experiences of the United States coal fired utility industry. A major finding of the analysis indicates that most explosions do not occur in proportion to the number of fires at a pulverized coal fired utility plant. The fire and explosion relationships for the industry divide the population into four categories. The paper discusses the characteristics of the categories and identifies the historically important trends.

ACKNOWLEDGMENT

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INTRODUCTION

During the past decade the U.S. utility industry has experienced a trend toward increasing usage of pulverized coal. With this increase, there has been an increase in explosion and fire problems. The resultant damage to personnel and property, besides the loss of revenue were prime considerations for EPRI to sponsor a study of the problems. The study included a historical survey and experimental testing.

This paper reports on the history of fires and explosions as experienced by the pulverized coal fired utility industry. The survey methods, analysis and resulting trends are discussed. In addition the conclusions and recommendations attempt to relate the historical information to the power industry as a whole.

SURVEY

Three separate utility surveys are combined in this work along with data from a 1980 U.S. DOE report.[1] The majority of the information comes from a survey conducted by Riley Stoker Corporation from late 1981 through early 1982. Additional information came from two pulverized coal fired utility surveys conducted by Brigham Young University in late 1979 and mid 1980 .[2]

The Riley Stoker survey used a questionnaire, together with telephone conversations and plant visits to gather data and observations from utility personnel. The survey distinguished between "fires" and "explosions". It sought a description of mill systems, unit hardware, and characterization of the coal. For the most part, the Riley Stoker survey respondents were plant managers and operators. In this report, the term "explosion" encompasses both severe puffs (structure deformation) and true explosions (containment breaching). The term "unit" designates a steam generator and its auxiliaries.

Based on the results of the survey materials, the industry frequency of fires and explosions has increased. The average survey values of 1.26 fires per year per unit (approximately five fires in four years) and 0.31 explosions per year per unit (approximately three explosions in ten years) show a rise over previous averages. Adjusted for the entire pulverized coal fired utility industry, there were over 300 explosion events in a year. Even though a small percentage were of the containment breaking type, the other events had the potential of being true explosions. In addition, there is a wide range in fire and explosion frequency from plant to plant. A number of plants reported fire or explosion free operation. At the other extreme, a few units reported as high as 13 fires per year or 3 explosions per year. These large ranges indicate that some plants are having severe problems with either fires or explosions or both. However, similar plants are operating essentially fire free and explosion free. The survey results reflect the situation at the end of 1981 and the maximum values may no longer apply. Since the survey, many plants have made modifications which have lowered their problem occurrences.

The database consists of 361 records for nonrepeated, individual generating plants belonging to 76 separate utilities. The breakdown of the database is shown in Table 1.

Item/Discrete Values	Count	Min	Max	Average
Records (non-repeated generating plants)	361			
Survey Source	361			
Riley Stoker Survey (RS) only	226			
BYU Survey 1979 (BYU1) only	19			
BYU Survey 1980 (BYU2) only	47			
RS/BYU1	12			
RS/BYU2	47			
RS/BYU1/BYU2	10			
Unit Start Up Year	361	1938	1981	1963
Unit Capacity	361	5	1080	306

Table I Database Population Statistics

ANALYSIS

To analyze the collected survey data, a statistical approach was taken rather than a review of problems on an event by event basis. The analyses of incidents are useful for an individual plant, but it is difficult to formulate correlations valid for the entire industry. There are many plant attributes that are important to fire and explosion questions, so that every plant is a unique configuration of values. The database and statistical analysis demonstrated trends, relationships and correlations valid for the entire coal fired industry. It is important to remember that the trends represent tendencies and are not absolute cause and effect relationships. Individual cases may not agree with the trends. However, when the industry is viewed as a whole, these trends are applicable.

The database contains plant information on 11 characteristics. These parameters were used to both categorize a plant's particular configuration and group the fire and explosion frequency data. The categories cover the following areas:

Plant Characteristics
— Unit operation mode

Mill System Characteristics
—Mill system operation mode
—Mill generic type
—Mill operation mode
—Mill capacity
—Number of mills per unit
—Mill age

Fuel Characteristics
—Coal type
—Coal volatile content
—Coal moisture content
—Coal ash content

The survey used the broad classification "other" to allow for any mill not of the ball or vertical spindle types. However, "other" mills always were identified by the utilities as attrition mills.

TRENDS

The analysis of the database shows that fire and explosion hazard levels are not simple functions of a small number of plant characteristics. If all units in the industry are viewed as a single group, there are no single parameters that distinguish the high risk units from the low. For all units in the industry, the 11 categories noted above are statistically equivalent and equally poor for differentiation. Therefore, viewing fire and explosion susceptibility as a function of a single category is ineffective.

In spite of the poor correlations, understanding the interaction of plant characteristics at a simple level of analysis is of value for a discussion of trends at a higher level of analysis. Figures 1 through 4 show the data for each of the 11 plant characteristics. It is important to note that, because of the general nature of this phase of the discussion, not all units will follow or agree with the overall trends. Recognizing the statistically weak influence of these parameters, the following trends were observed:

1. Unit Operation Mode: Base loaded units have fires twice as often as cycling units, but both types of units report essentially equivalent explosion frequencies. When the coal type is considered, the bituminous fired units maintain the same relationship for fire frequencies of base to cycling units. However, subbituminous coals produce an increase in the fire frequencies for both modes. The explosion frequency of units using bituminous coals are equivalent for base and cycling modes. Subbituminous fired base units experience explosions at over two times the rate of the cycling units.

2. Mill System Operation Mode: Direct fired units have twice the fire frequency of bin storage units. Conversely, the bin storage units have twice the explosion frequency as direct fired units. Differentiation of the direct fired units by coal type shows that subbituminous fired units have fire and explosion frequencies twice as high as those of the bituminous fired units.

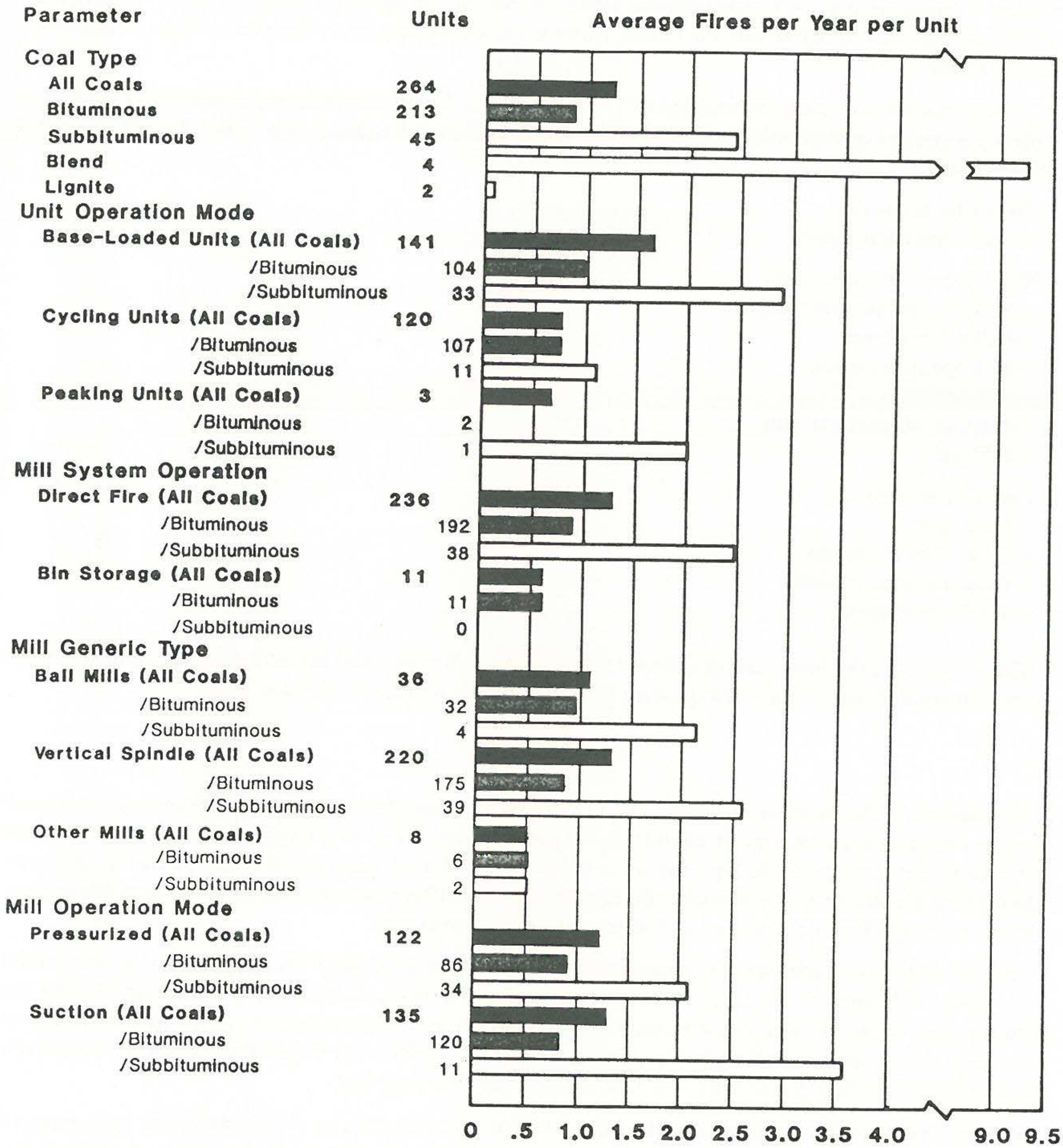


Figure 1 Average Fires per Year per Unit for Five Classification-type Parameters

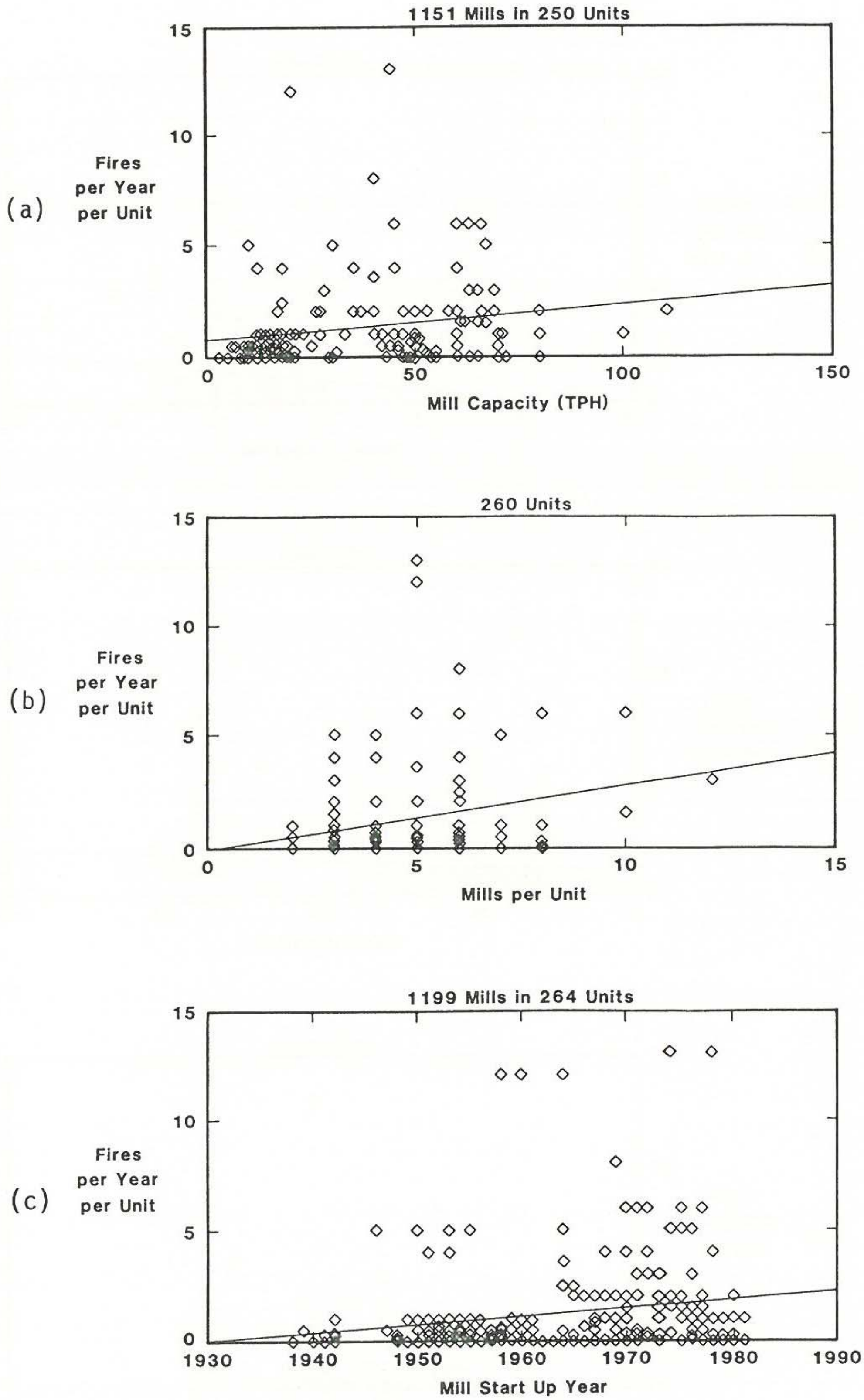
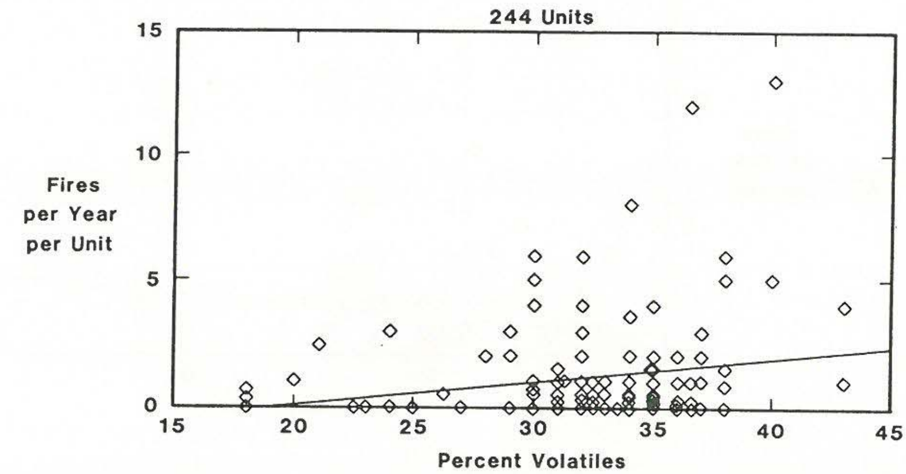
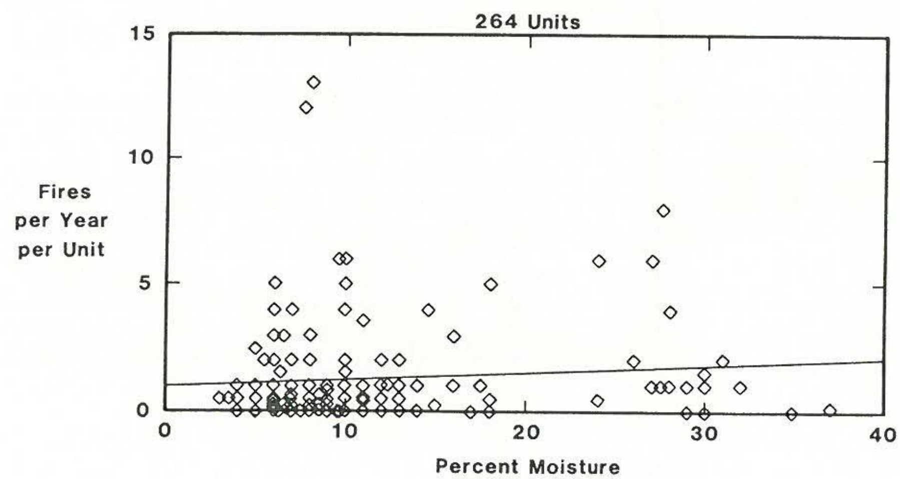


Figure 2 a,b,c   Fires per Year per Unit for Six Range-type Parameters

(d)



(e)



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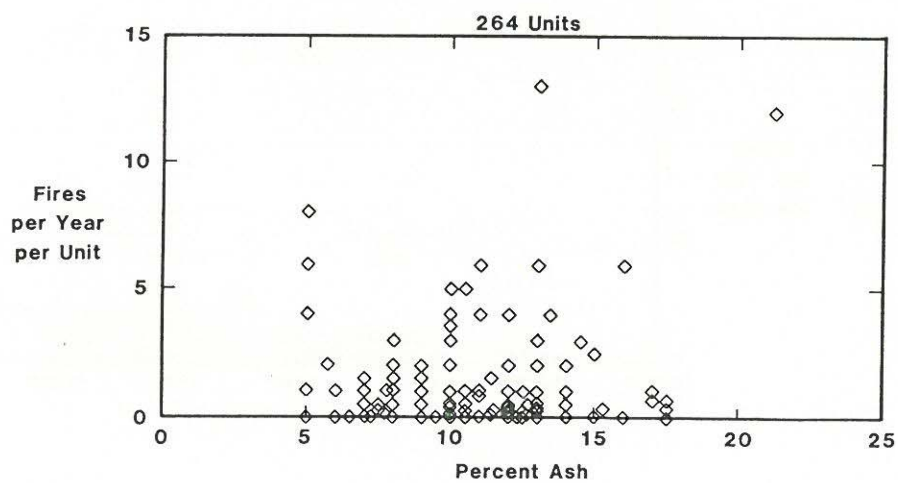


Figure 2 d,e,f   Fires per Year per Unit for Six Range-type Parameters

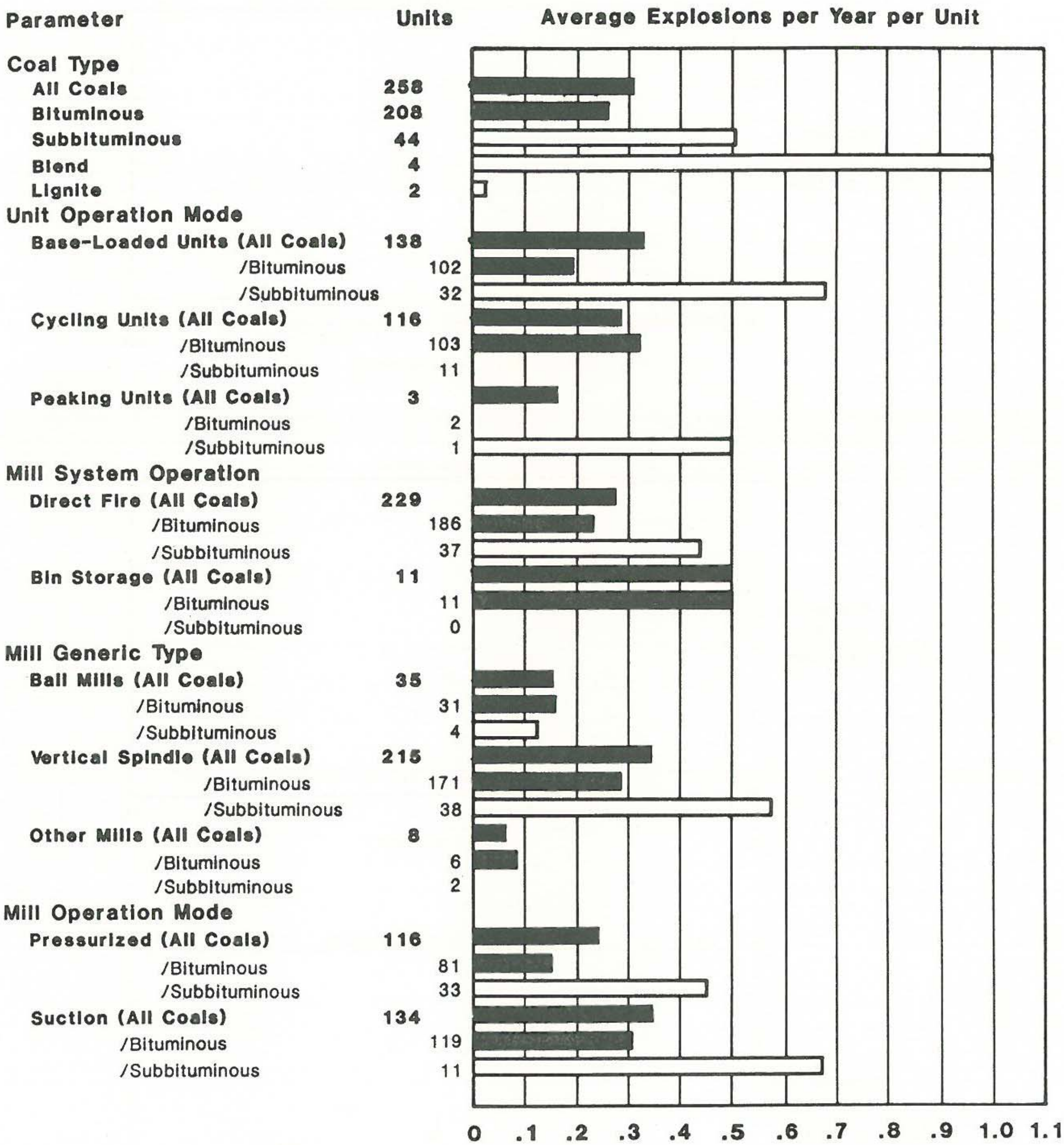
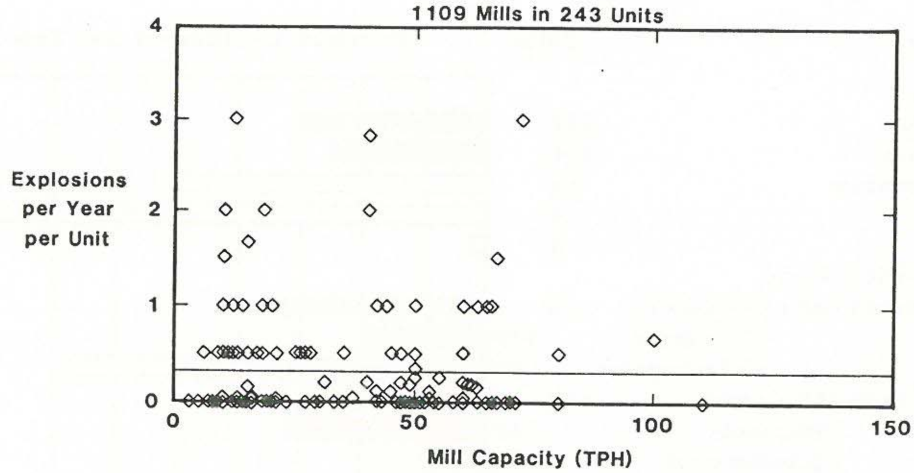
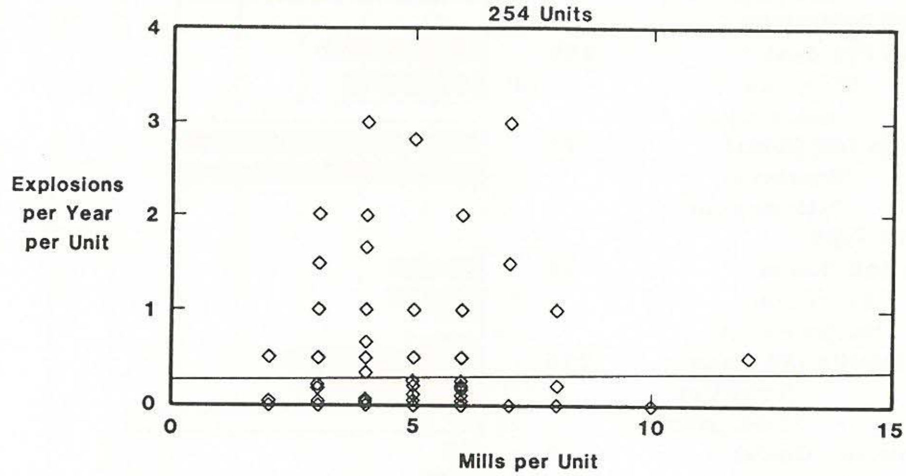


Figure 3 Average Explosions per Year per Unit for Five Classification-type Parameters

(a)



(b)



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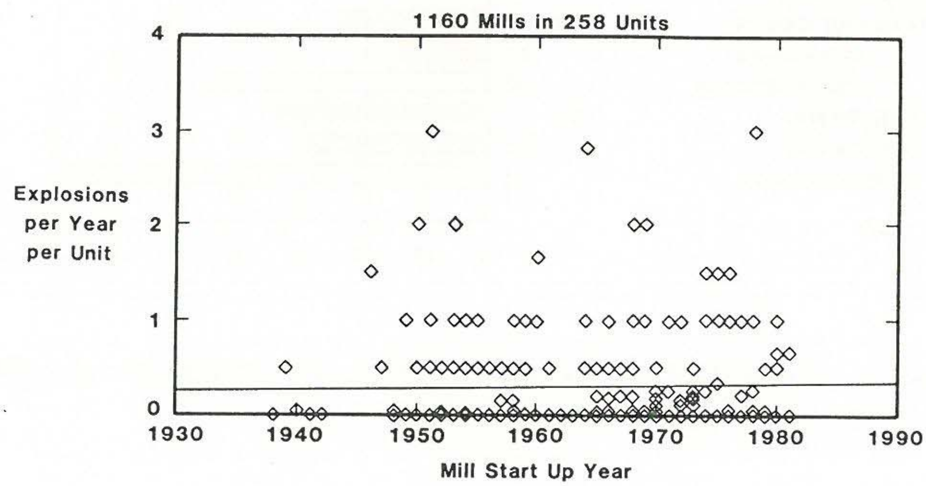
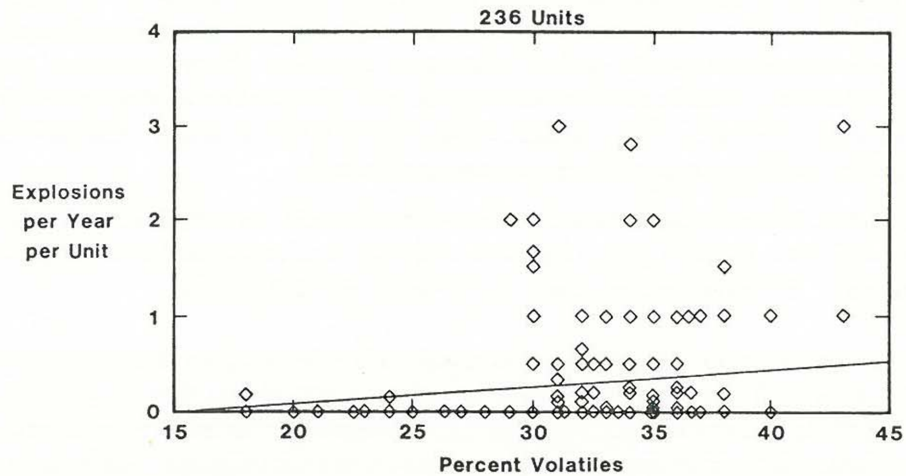


Figure 4 a,b,c Explosions per Year per Unit for Six Range-type Parameters

(d)



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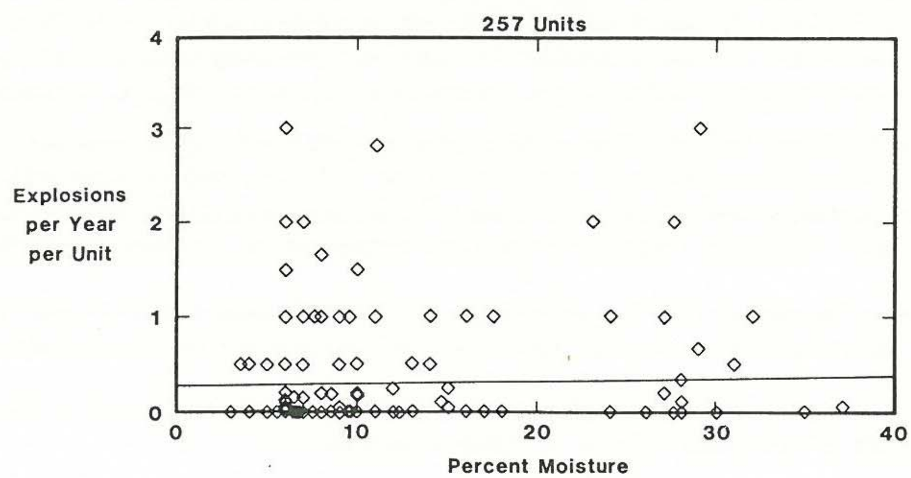

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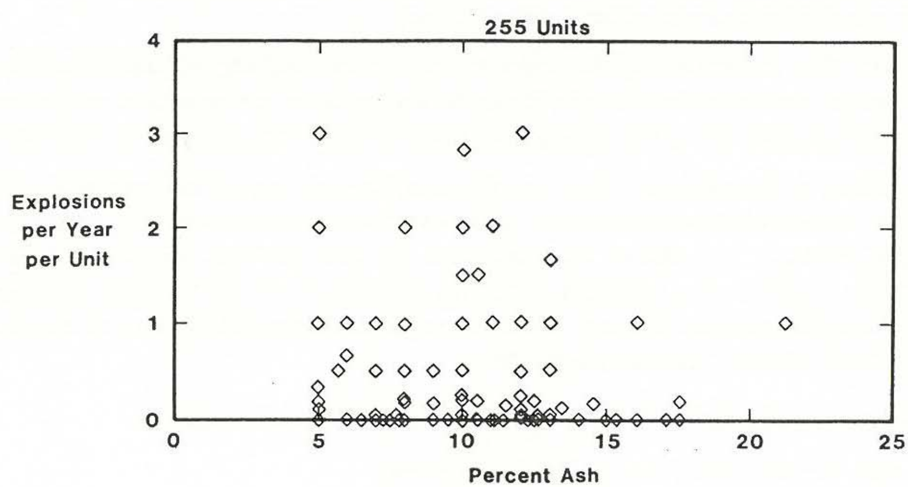

Figure 4 d,e,f   Explosions per Year per Unit for Six Range-type Parameters

3. Mill Generic Type: Both ball and vertical spindle mills have shown essentially equivalent fire frequencies, and are approximately twice as large as the fire frequency of the attrition mills. The explosion frequency for vertical spindle mills is about twice that of the ball mills and about five times that of the attrition mills. With bituminous coals the vertical spindle and ball mills show equivalent fire and explosion frequencies while the attrition mills have lower frequencies. Vertical spindle mills using subbituminous coals have about twice the fire frequency of the ball mills. Also, subbituminous grinding vertical spindle mills have about twice the explosion frequency of bituminous grinding vertical spindle mills.

4. Mill Operation Mode: Pressurized and suction operation mills have equivalent fire frequencies. The suction operation mills have a slightly higher explosion frequency than pressurized mills. The trend is re-emphasized by the coal type. Subbituminous coals accentuate the difference.

5. Mill Capacity: Generally, fire frequency increases with mill capacity and explosion frequency is independent of mill capacity. However, by separating bituminous and subbituminous coal fired systems a trend is observed. Units firing bituminous coals have a reduction in explosion frequency with an increase in mill capacity. Units firing subbituminous coals experience an increase in explosion frequency with an increase in mill capacity.

6. Number of Mills per Unit: Both fire and explosion frequency increase with an increasing number of mills per unit. Subbituminous coal accentuates the increase in fire frequency with an increase in the number of mills per unit. Explosion frequency trends produce two opposing conditions. Units firing bituminous coals fired units show a slight decrease in explosion frequency with increasing number of mills per unit. However, subbituminous fired units show a sharp increase in explosion frequency with increasing number of mills per unit.

7. Mill Age (Mill Start Up Year): Fire frequency goes up slightly with mill newness and explosion frequency appears to be independent of mill age. As with the number of mills, subbituminous coals accentuate the increase in fire frequency with mill newness. Explosion frequency has a slight decrease with mill newness for bituminous coals. Conversely, explosion frequency increases with mill newness for subbituminous coals.

8. Coal Type: The subbituminous coals have fire and explosion frequencies of about twice those of bituminous coals. The fire and explosion values of lignite coals were ignored due to the extremely small population.

9. Coal Volatility: Both fire and explosion frequency increase with an increase in volatility content, but these trends are as weak statistically as the others categories.

10. Coal Moisture: Fire frequency increases slightly and explosion frequency remains unchanged with increases in coal moisture. Overall, there is a connection between moisture and mill age. The new (younger) units have a trend toward using higher moisture coals.

11. Coal Ash: Fire and explosion frequency are higher for medium ash coals than for low and high ash coals. This trend is dominated by the units firing the high volatile, low moisture, subbituminous coals. These coals fall into the medium ash group and appear to have higher than normal fire and explosion frequencies.

A major finding of the analysis is that the historical fire and explosion experience of the U.S. coal fired utility industry does not follow a commonly held view that explosions occur in proportion to the number of fires at a unit. Figure 5 is a plot of the explosions per year per unit versus the fires per year per unit for 255 units (1147 mills) of the database reporting both numbers. Rather than showing a linear or single monotonic relationship between fires and explosions superimposed with the scatter of experimental data, Figure 5 shows four fairly distinct concurrence modes.

Coal fired utility units fall into one of the four modes defined as follows:

Mode 1: Low fire frequency, low explosion frequency
Mode 2: High fire frequency, low explosion frequency
Mode 3: Low fire frequency, high explosion frequency
Mode 4: High fire frequency, high explosion frequency (approximately one explosion for every three fires).

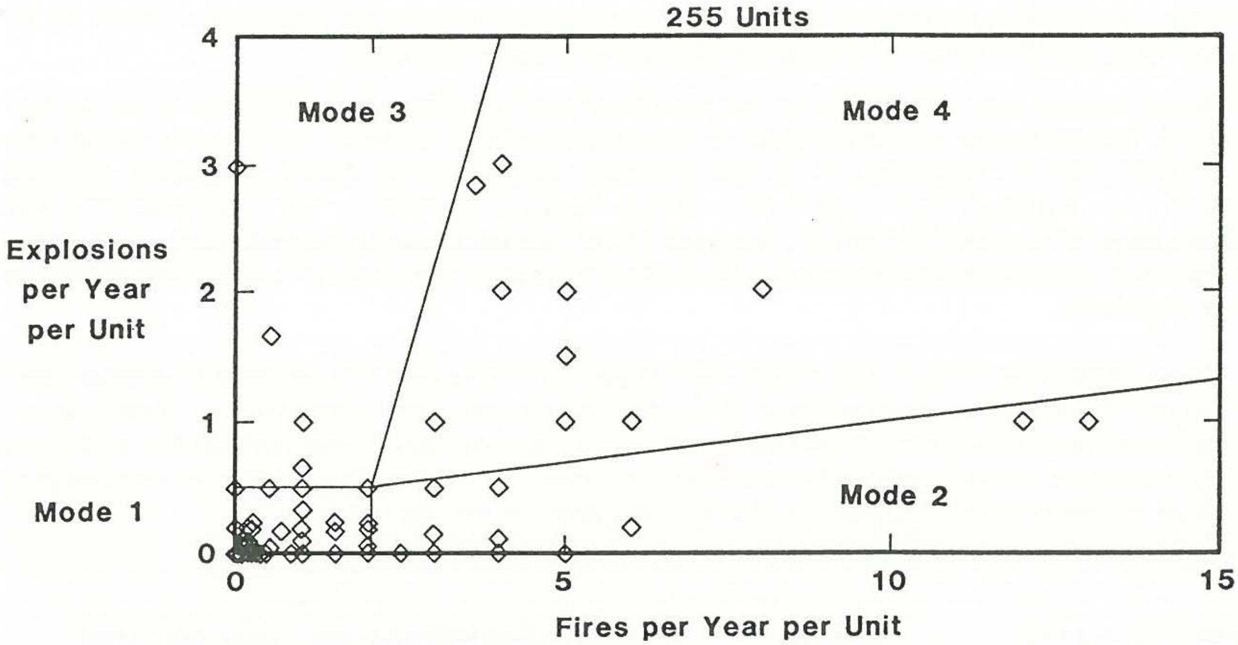

Figure 5 Explosions per year per Unit versus Fires per Year per Unit

Mode 1, the desirable pattern, contains 78 percent of the population. These units represent every category showing that there is no barrier to safe plant operation. However, this mode does contain a significantly higher proportion of the database's oldest plants. The trend that older plants have fewer fires and explosions may indicate that more operating and maintenance experience produce a safer facility. It may also indicate that smaller units firing bituminous coals are safer.

Mode 2 contains about seven percent of the population. These plants have a higher proportion of certain plant conditions and may be represented by one or a combination of characteristics. The characteristics are base loaded units, middle aged units, large capacity units, pressurized mills, medium volatile coals, high ash coals or subbituminous coals.

Mode 3 tends to be characterized by base loaded units, new mills, suction operated mills, vertical spindle mills, medium volatile coals, high moisture coals, low ash coals, or subbituminous coals. This group contains about nine percent of the U.S. coal fired utilities.

Mode 4, the proportional fire and explosion pattern, is the smallest of the groups with only six percent of the population. This group is characterized by plants with a larger number of mills, vertical spindle mills, medium volatile coals, high moisture coals, high ash coals or subbituminous coals.

Areas where the survey conveyed very little information dealt with detection, suppression and inerting systems. Only 117 units identified a detector type. Of the units that were identified only 15 (four percent) reported using carbon monoxide (CO) monitors. Units with CO monitoring systems had a fire per year per unit frequency four times that of the average. However, no distinction was made for fire experience before and after installation of the detectors. It is not possible to say whether the high frequency means the detector is more effective at detecting fires that previously went undetected, or the detector was installed in a unit known previously to have high fire frequency. There is an interesting feature of temperature monitoring and the frequency of fires and explosions. As alarm temperature settings are increased, the reported fire frequencies decrease. However, the explosion frequency was independent of the alarm temperature setting.

The survey sought information on the type of fire extinguishing agents currently employed. One hundred eighty-one units identified 13 agents or combinations of agents including "None". The effectiveness of the systems was neither questioned nor reported. From a historical viewpoint, no correlation or trends can be noted about the effectiveness of currently employed fire extinguishing agents.

Because inerting agents are used to prevent something from happening, explosion frequency can be used to gauge the effectiveness of inerting agents in preventing explosions. However, there was not enough data available to allow for subdivisions by the four previously discussed modes. Four inerting agents including "None" were identified. Figure 6 shows the explosion frequency for "CO_2","N_2", and "Steam", as well as the groups "None" and "Unknown". The group "None" are units reporting no inerting agents. The group "Unknown" are the units that left the entry blank. Both "Unknown" and "None" contain units of low and high frequencies.

Almost 90% of the "None" and "Unknown" categories are comprised of units firing bituminous coals, while the "Steam" group contains almost 95% subbituminous coal users. Historically, the steam group is experiencing approximately 1.5 times as many explosions as the group that is doing nothing. The group using CO_2 is similar to "None" and has half the explosion frequency of steam. The survey does not distinguish between explosion experience before or after the installation of inerting systems.

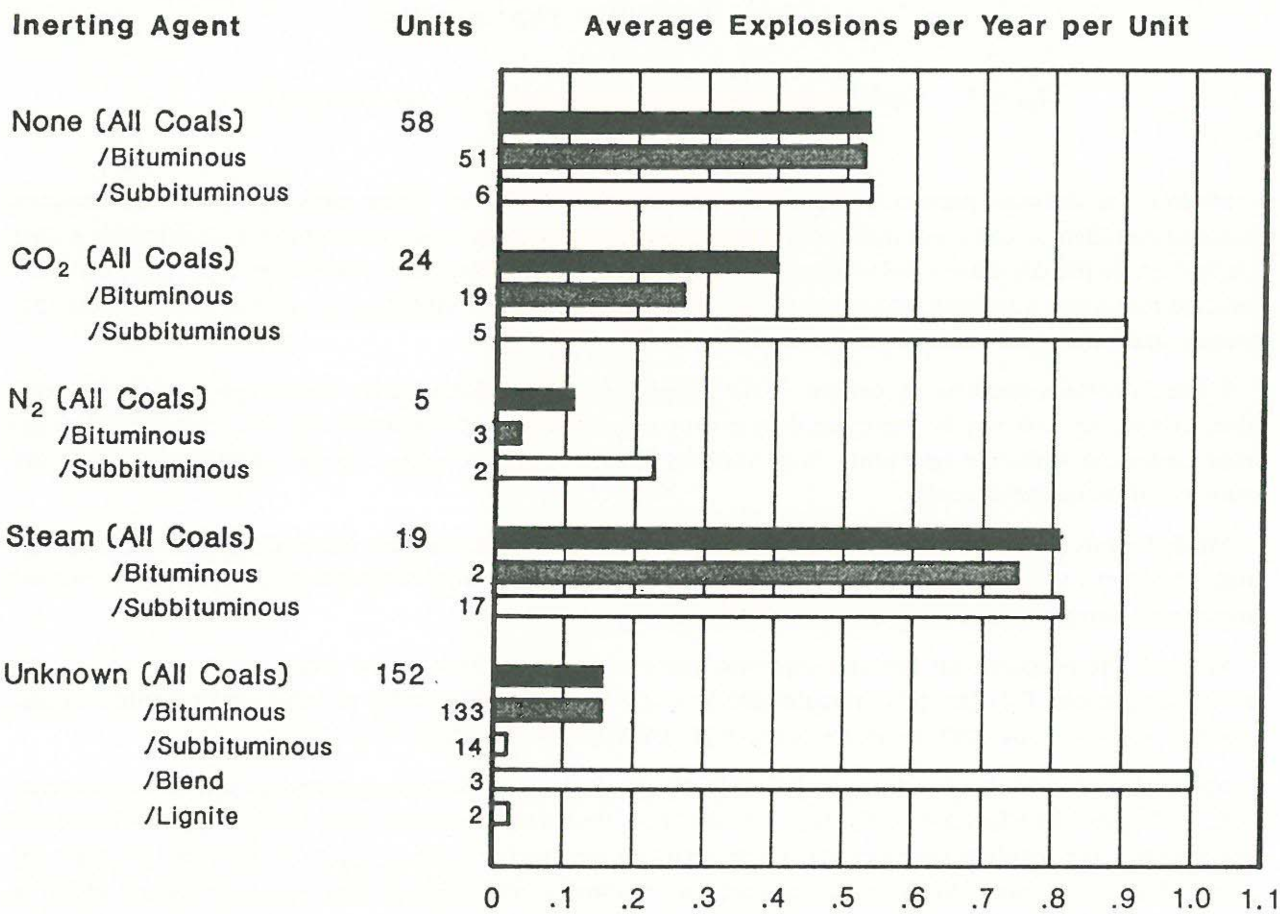

Figure 6. Average Explosions per Year per Unit versus Three Inerting Agents Used by U.S. Utilities

CONCLUSIONS

The conclusions sited in this report resulted from a statistical analysis of the survey process. There is no single condition or combination of conditions that is always present in fire or explosion situations. Therefore, the conclusions are not absolute and may contain exceptions. The one general conclusion was that not all fires cause explosions but that all explosions were caused by fires.

Fire and Explosion Relationships

The historical data shows that the relationship of frequencies of fires and explosions fall into four modes. The first mode contains units which report a low frequency of both fires and explosions, and is about 78 percent of the coal-fired utility steam generators. The second mode contains units with a high fire frequency but a low explosion frequency, and is about seven percent of the population. The third mode is about nine percent of the survey group and contains units with a low fire frequency but a high explosion frequency. The fourth and smallest mode contains units with high frequencies for both fires and explosions, which is the remaining six percent. These results indicate that over 15 percent of the units in the United States have an extremely serious explosion problem, while 22 percent of the coal-fired utilities have major problems with fires or explosions. Because of inadequate detection, some units reporting low fire frequencies may be experiencing fire problems and are not recognizing the fires.

Unit Operation

The plant operation methods appear to be related to the frequency of events. The more experienced plants have lower explosion and fire frequencies. However, complicating this statement are the facts that unit capacity, number of mills, and mill capacity are smaller for older units than newer units. The type of coal, type of mill operation, and the plant operation mode are additional factors affecting experience. Base loaded units have more than twice the reported fires as cycling and peaking units. However, whether the units are base loaded or cycling seems to have no bearing on the frequency of explosions. In addition, interviewers reported that plants that have instituted improved maintenance or operating procedures have lowered their frequencies of fires and explosions.

Mill Systems

Direct-fired boilers report more than twice the fire frequency of bin storage fired boilers. Because fire detection was not used at the majority of bin storage plants, it is possible that the systems have a higher frequency of fires. Direct-fired systems have exhibited half the explosion frequency of bin storage system. This is reverse of the fire situation. Because flue gas is used as the pneumatic transport medium in bin storage systems, the plants may assume an inert gas is present. However, low loads, leakage in the system or malfunctioning dampers can increase oxygen concentrations to levels suitable for explosions.

Mill Type and Operation Mode

There are three types of mills; vertical spindle, ball and attrition. The fire frequency of the ball and vertical spindle mills are similar. The attrition mills in the survey had a fire frequency of less than one-half the other two types. Attrition mills are not widely used in the utility industry and represent a very small sampling of the total survey population. The survey results showed no apparent distinction between pressurized and suction mill operation with regard to the frequency of fires. In so far as explosions are concerned, vertical spindle mills have shown a higher frequency of explosions than the other two types. Characteristics beyond the mill type are involved. Many vertical spindle mills are in suction operation and grind subbituminous coals. The interrelationship of various factors make it is impossible to determine how sensitive these mills are to subbituminous coals. Pressurized mill operation has shown a lower frequency of explosions than suction mill operation for all types of mills. Once again, the type of fuel and other characteristics affect the statistical picture.

Coal Type

The type of coal is a major factor in both fire and explosion frequencies. Units using subbituminous coals show twice the frequency of fires and explosions as units with bituminous coals. But as a single characteristic for differentiation purposes, it is statistically no better than other unit characteristics. Firing a subbituminous coal does not indicate a hazardous situation by itself. There are many utilities operating with subbitminous coals that are reporting fire and explosion frequencies below the norm. However, when joined with the other characteristics, subbituminous coals appear to exaggerate any sensitive condition. The survey sampling with lignite is too small to allow any evaluation. The blending of coals, though it can not be used statistically, does indicate possible operational problems. Blends that are not homogenious force mill operation to react to changes in fuel characteristics. Follow up interviews revealed that units that have converted to washed coal, for economic or environmental reasons, have had a marked decrease in fires and explosions as a side benefit.

Inerting Systems

The survey responses showed that less than one-fifth of all units use inerting systems. Comparing all other units to the units with inertants, plants without inerting systems have lower explosion frequencies. With every inerting agent the frequency of explosions is higher with subbituminous coals. However, the information does not differentiate between event experiences before or after inertant system installations. It is not known if inertants were instituted to correct a high explosion frequency or if the reported frequency can be considered normal for that combination of characteristics. The survey information on inertants is not conclusive, but does reveal concerns that must be investigated further.

Extinguishing Agents

An assessment on fire extinguishing agents effectiveness based on survey responses was difficult. The plant evaluations of how well an agent worked is essentially a subjective opinion. For a particular fire and agent deployment, the operator cannot compare how quickly or safely the fire would have extinguished without the agent. Plants reported the use of water, carbon dioxide, saturated steam, nitrogen and flue gas for fire extinguishing with varying degrees of success. Based on the data it was not possible to reach an objective conclusion.

Fire Detection Systems

Interviews were conducted with utilities employing various fire detection systems. Presently there is no standard method of detecting a fire or determining what is a fire. Some plants define a fire when equipment paint peels or the metal glows red. The methods that were reported to be most effective in early detection are carbon monoxide (CO) monitoring and differential temperature monitoring across the mill system. The differential system compares the mill system inlet air conditions with the mill system outlet air conditions. There have been conflicting reports on the effectiveness of various systems. However, some utilities, after expending extensive efforts, report that their CO detection systems are reliable.

RECOMMENDATIONS

The recommendations given in this report are not directed at any specific plant or utility and the suggestions are not intended to alleviate a specific concern. Care must be taken when enacting any modification or change. Even though the discussions above deal with improving problem conditions, not all changes are beneficial. Because of the complicated relationship of the variables governing the creation of fires and explosions, the initiation of system modifications without a thorough analysis may produce results directly opposite of those desired.

Detection

Because explosions are caused by fires, extinguishing fires will reduce explosions. However, a fire can be extinguished only if it is detected. Speedy detection of fire is vital to the prevention of compounding a problem. As a mill fire becomes large, the controls automatically reduce the temperature of the primary air. With high coal flow, there is less and less drying until the wet fuel starts to cake and plug the system. Then fuel flow is impeded and the conditions become ideal for an explosion. Quick detection can result in proper action, preventing a serious incident. The survey reports the most successes with a differential temperature and CO monitoring systems. Problems that were reported early in the survey on CO monitoring appear to have been alleviated.

Procedures

There is a correlation of lowered fire and explosion frequencies with improvements in maintenance and operating procedures. Also, equipment manufacturers periodically modify their recommended maintenance procedures and replacement parts. It is important that utilities with concerns review the plant maintenance and operating procedures and periodically contact the equipment manufacturers.

Coal Type

Fuel changes should not be made until after a complete analysis of the fuel has been made to determine the coal's reactivity. Blended fuels should be as homogenious as possible. Because the characteristics of the coal show one of the strongest correlations for fire frequency, as well as explosion frequency, any changes in coal characteristics supply will have an effect on the plant's frequency of fires and explosions. In addition, plants with a high fire frequency may wish to consider the introduction of washed coal.

Inerting Systems

Because of the concerns developed in the survey, there is a question of using any inerting system. However, if a utility determines that an inerting system is necessary, extensive instrumentation controls and training are required. Inerting will not extinguish fires and is no guarantee of eliminating explosions, but with extreme care, the frequency of explosive events may be reduced.

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