Eastern Kentucky University
Encompass

Online Theses and Dissertations | Student Scholarship

2011

Workplace Explosions: A Comparison of the Mine Safety and Health Administration and the Occupational Safety and Health Administration

Jessica Dawn Burba
Eastern Kentucky University

Follow this and additional works at: https://encompass.eku.edu/etd

Part of the Occupational Health and Industrial Hygiene Commons

Recommended Citation

Burba, Jessica Dawn, "Workplace Explosions: A Comparison of the Mine Safety and Health Administration and the Occupational Safety and Health Administration" (2011). *Online Theses and Dissertations*. 24.
https://encompass.eku.edu/etd/24

This Open Access Thesis is brought to you for free and open access by the Student Scholarship at Encompass. It has been accepted for inclusion in Online Theses and Dissertations by an authorized administrator of Encompass. For more information, please contact Linda.Sizemore@eku.edu.

WORKPLACE EXPLOSIONS: A COMPARISON OF THE MINE SAFETY AND HEALTH ADMINISTRATION AND THE OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

By

Jessica Dawn Burba

Thesis Approved:

Chair, Advisory Committee

Member, Advisory Committee

Member, Advisory Committee

Dean, Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a masters degree at Eastern Kentucky University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made. Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in [his/her] absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ______________________

Date April 6, 2011

Workplace Explosions: A Comparison of the Mine Safety and Health Administration and the Occupational Safety and Health Administration

By

JESSICA DAWN BURBA

Bachelor of Science
Eastern Kentucky University
Richmond, Kentucky
2009

Submitted to the Faculty of the Graduate School of
Eastern Kentucky University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 2011

Copyright © Jessica Dawn Burba, 2011

All rights reserved

DEDICATION

This thesis is dedicated to my extraordinary parents without whom I would not be the woman I am today.

ACKNOWLEDGMENTS

I would like to thank my amazing friends and family for their unending love and support throughout this thesis process. Thank you for listening to my rambling and complaining when the stress was getting to me and for having faith in me when I did not. It was your constant encouragement that allowed me to continuously motivate myself to further my education and complete this thesis. You will never know how much it means to me and I will be forever grateful.

A special thank you to my thesis chair, Professor Scotty Dunlap, for being patient with me and putting up with my constant questioning and stress and not allowing me to give up. Without your guidance, mentoring, and faith in my abilities I would not have been able to accomplish the completion of this tedious thesis process. You are a great mentor and role model and I know you will continue to be an important asset to Eastern Kentucky University.

Thank you to my college professors for your guidance and knowledge over the past several years. You have given me an amazing education; a gift that will follow me throughout my professional life.

Thank you my very understanding boss, Steve Hays, for giving me the support and time needed to work on my thesis. Thank you for having faith in me. Your support and understanding made this thesis a little more achievable.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES

TABLE **PAGE**

CHAPTER I

BACKGROUND

Mining Operations

When land elevation is too high and coal seams are too deep for surface mining, underground mining techniques are implemented. The majority of underground coal mining occurs east of the Mississippi River. Drift mines, slope mines, and shaft mines are the three types of underground mining that are used depending on the topography of the land. Drift mines are used when coal deposits are at the surface of a hillside. These mines are driven into the seam horizontally. When a coal bed is too deep for surface mining, but located close to the surface, the engineering of a slope mine can be used. A slope mine is a mine with a downward incline into the coal seam from the surface. Shaft mines are the most commonly used mines and are necessary for mining deep coal beds. Machines are used to excavate shaft mines by cutting vertical shafts through the ground to the coal bed (KET, 2005).

Currently in the mining underground industry there are two types of mining processes in use; Longwall mining and Room and Pillar mining. Longwall mining comprises approximately 31 percent of all underground coal production.

> "In longwall mining, a cutting head moves back and forth across a panel of coal about 800 feet in width and up to 7,000 feet in length. The cut coal falls onto a flexible conveyor for removal. Longwall mining is done under hydraulic roof supports (shields) that are advanced as the seam is cut. The roof in the mined out areas fall as the shields advance" (UMWA, n.d.a, para. 1).

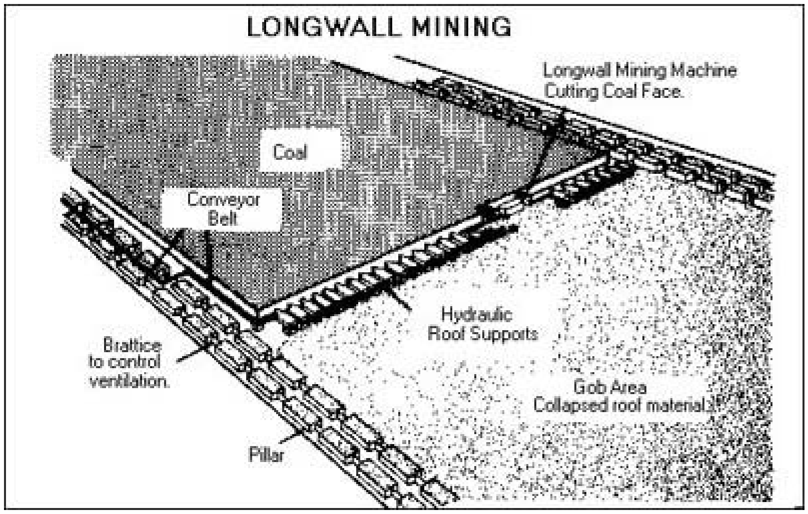

Figure 1. Longwall Mining

Source: Drawing depicts Longwall Mining operations. Adapted from "Who We Are, Where We Work," by United Mine Workers of America, Retrieved April 22, 2010 from http://www.umwa.org/index.php?q=content/longwall-mining.

The greatest percentage of underground mining is done using the Room and Pillar method. Room and Pillar mining occurs when

> "rooms are cut into the coal bed leaving a series of pillars, or columns of coal, to help support the mine roof and control the flow of air. Generally, rooms are 20 to 30 feet wide and pillars are 100 feet wide. As mining advances, a grid-like pattern of rooms and pillars is formed. Workers drive bolts of up to eight feet long in the roof of the rooms to keep the rock above the coal seam from falling in. When mining advances to the end of a panel or property line, retreat mining begins. In retreat mining, the workers mine as much coal as possible from the remaining pillars until the roof falls in. When retreat mining is completed, the mine area is abandoned" (UMWA, n.d.b, para. 1).

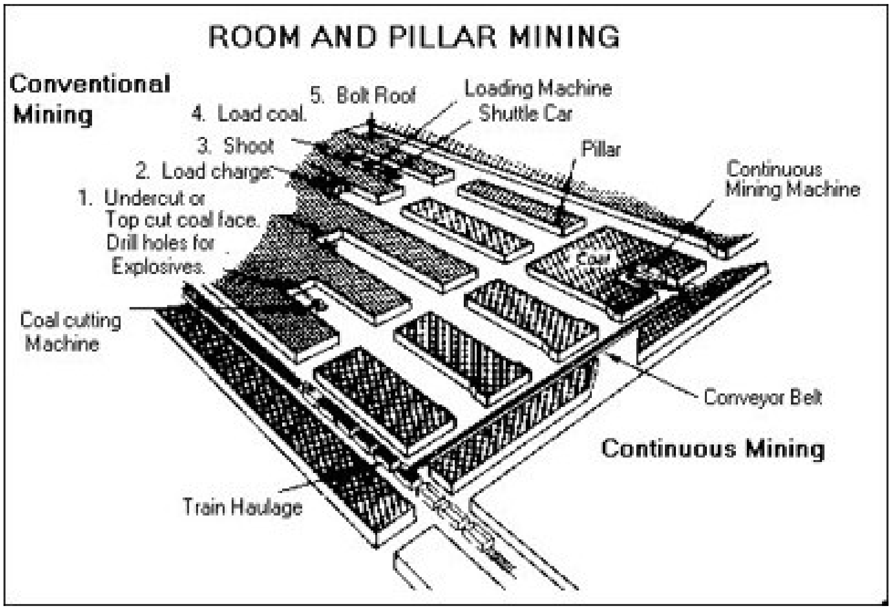

Figure 2. Room and Pillar Mining

Source: Drawing depicts Room and Pillar Mining operations. Adapted from “Who We Are, Where We Work,” by United Mine Workers of America, Retrieved April 22, 2010 from http://www.umwa.org/index.php?q=content/room-and-pillar-mining.

Room and Pillar mining is done using either conventional mining or continuous mining. Conventional mining is the oldest method of mining. During the conventional mining process cutting, drilling, and blasting of the coal seam is performed and the produced coal is loaded into cars for transport. The most widely used form of underground mining is continuous mining. This process requires the use of a continuous miner. A continuous miner is a machine that makes drilling and blasting in mines obsolete by cutting the coal from the face of the mine (UMWA, n.d.b).

Sugar Refinery Operations

Sugar is a common household commodity. People use it in their daily lives to sweeten things from coffee to oatmeal, but few of us may know where it comes from or how it is made (Central Sugars Refinery, 2008). Today, well over 120 tons of sucrose, also known as table sugar, is produced in 121 countries. Sugar cane makes up 70 percent of this production while sugar beet makes up the remaining 30 percent. Sugar cane typically grows in tropical climates. It very much resembles the bamboo cane with its height and large stems. Sugar beet however is a root crop that looks very similar to a large parsnip and is largely grown in mild weathered northern zones (SKIL, n.d.a). After the sugar cane and sugar beet are harvested they are shipped to a refinery where they are then turned into sucrose (SKIL, n.d.b).

"The refining process simply separates natural sucrose from the plant material without bleaching or chemical manipulation" (Sugar Association, n.d, para. 2). The processes to refine sugar cane and sugar beet are slightly different from one another. To begin refining sugar beet, the beet is cut into thin chips increasing the beet's surface area allowing more sugar to be extracted. To extract the sugar, the beets are put in a diffuser of hot water for close to one hour. "The diffuser is a large horizontal or vertical agitated tank in which the beet slices slowly work their way from one end to the other and the water is moved in the opposite direction" (SKIL, n.d.c, para. 2). As the water moves around, a stronger sugar mixture called juice is formed. After the beets have been diffused they are still wet and that water contains valuable sugar. To extract the remaining juice, the beets are pushed through screw presses. Once all the juice has been squeezed from the beets, chalk is thrown in clumps into the juice to clean it up before sugar production. These clumps absorb all of the non-sugars in a process called carbonatation. The chalk is then removed, thus removing all non-sugars. The juice is then turned into syrup by boiling off the water through evaporation. The syrup is then placed in a large pan, typically sixty tons or larger, and the remaining water is boiled out of the sugar until sugar crystals can grow. Crystal growth is sometimes helped by dusting with sugar dust. Once the crystals have grown they are placed in a centrifuge and tumbled until the sugar and mother liquor are separated. Lastly the sugar crystals are then dried one last time with hot air. The sugar, sucrose, is now ready for storage (SKIL, n.d.c).

The refining of sugar cane is nearly identical to sugar beet refining process with only a few differences. To begin, the cane juice is extracted from the sugar cane by wringing it through a sequence of hefty roller mills or by putting it in a diffuser. After the juices are extracted, what is left of the sugar cane is sent off to be used in the boilers (SKIL, n.d.b) whereas the leftover beets cannot be used in the boilers (SKIL, n.d.c). The juice still contains quantities of unwanted sediment at this point. Slaked lime is then used to remove the unwanted sediment from the juice. After all the sediment is removed, the juice is thickened into syrup by evaporation, meaning the water is boiled off using steam. The syrup is then put in a large pan and the remaining water is boiled off until the mixture is dry enough for sugar crystals to begin forming. Sometimes workers will sprinkle sugar dust to induce crystal growth. After the crystals have grown they are placed in a centrifuge and spun to separate the crystals from the mother liquor. Once separated, the crystals are dried one final time with hot air and then put in storage (SKIL, n.d.b).

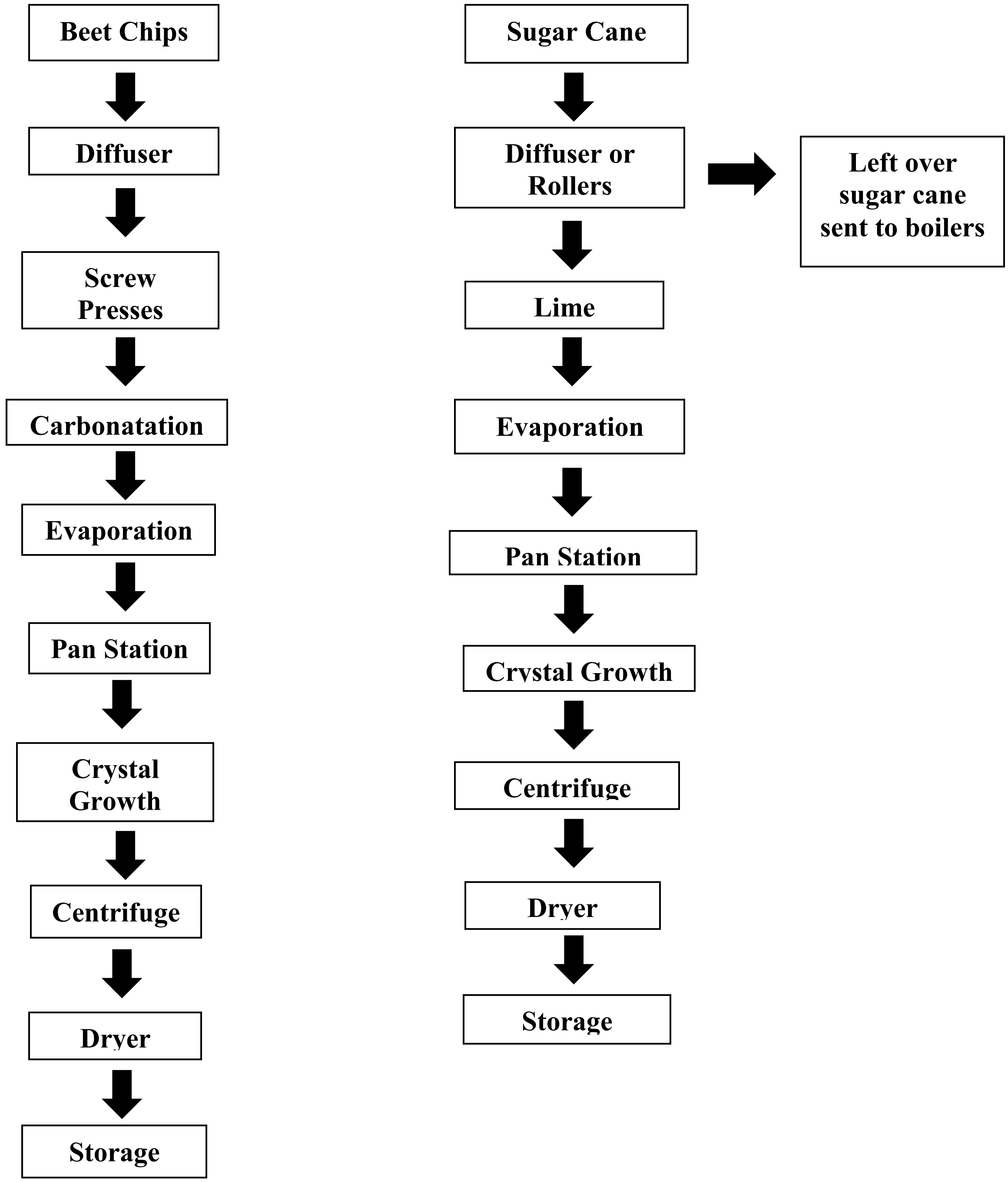

Figure 3. Sugar Refining

Source: Diagram depicts sugar refining processes. Adapted from “Production: Process diagram,” by Skidel Sugar Refinery, Retrieved March 6, 2011 from http://www.ssf.by/eng/proc/proc_3.html.

Statement of the Problem

Due to the dangerous nature of mining processes there are many hazards associated with the mining environment. The mining of bituminous coal (soft coal) is no exception. A major hazard of bituminous coal mining is explosion caused from the build-up of gas and combustible coal dust. Coal mine explosions date back to 1839 when the first major coal mine explosion in the U.S. occurred at the Black Heath Mine in Virginia, killing 53 miners (Ulery, 2008). Despite past incidents and known hazards, these disasters continue to occur with the most recent mine explosion on April 5, 2010. This explosion occurred at the Upper Branch mine in West Virginia and resulted in the fatality of 29 miners, the worst coal mine explosion in nearly 40 years (CNN, 2010). Since 1906 explosions have been the cause of approximately 10 percent of all fatalities in underground coal mining (Skow, Kim, & Deul, 1980).

In the sugar refining industry, combustible dust created through processing sugar is a major explosive hazard. The first well-recorded dust explosion is said to have occurred in December of 1785 in Italy due to the combination of aerated, dry wheat flour, and a lit oil lamp. Combustible dust explosions have been occurring for centuries (Weirick & Manjunath, 2009). In 2006 the Chemical Safety Hazard Investigation Board (CSB) reported that there have been approximately 280 dust explosions in the past 25 years resulting in more than 700 injuries and nearly 119 deaths (OSHA, 2009).

Purpose of the Study

The purpose of this study is to examine the explosive hazards of sugar refineries and underground bituminous coal mines by examining the activities and causes of the 2006 Sago mine explosion and the 2007 Imperial Sugar refinery explosion. I will then compare and contrast how the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) each responded to the explosions under their respective jurisdictions. This will allow me to determine if there are differences in the enforcement activity of the two agencies when confronted with similar catastrophic events.

Potential Significance

This study will bring the disastrous effects of occupational explosions to the surface and allow others to understand their devastating effects and how to prevent such occurrences. The ways OSHA and MSHA responded will be studied to see if these agencies are effectively accomplishing their mission.

Definition of Terms

1. *Bituminous coal*, soft coal, is identified by its low fixed carbon rate, high volatile mater, agglomerating, and slagging characteristics (Environmental Protection Agency, 1998).
2. *Combustible Dust* is defined as fine particles that present an explosion hazard when suspended in air in certain conditions (OSHA, n.d.b, para.1).
3. *Contributory Citation* is a citation issued for a condition that leads to the causes and effects or the severity of an incident (MSHA, 2007b, p. 189).
4. *Deflagration* is defined as a rapid combustion without the generation of a shock wave (Geddie, n.d, p. 13).

5. *Dense phase conveying* is a process when more tightly packed slugs of sugar are moved slowly in a way that minimizes dust formation and allows less room for air (Earls, 201, para. 23)).
6. *Explosion* is defined as the bursting or rupture of an enclosure or a container due to the development of internal pressure from deflagration (Geddie, n.d, p. 13).
7. *Float Coal Dust* is defined as suspended fine coal dust (NIOSH, 2006).
8. *Intrinsically safe* means incapable of releasing enough electrical or thermal energy under normal or abnormal conditions to cause ignition of a flammable mixture of methane or natural gas and air of the most easily ignitable composition (30 CFR 18.2, para. 24).
9. *Methane* is defined as an odorless, colorless, and nonpoisonous gas that naturally occurs in coal mines due to the formation of coal (Skow, Kim, & Deul, 1980).
10. *Non-contributory Citation* is a citation issued for a condition that does not lead to the causes and effects or the severity of an incident (MSHA, 2007b, p. 189).
11. *Rock Dusting* is defined as the process of applying a combination of incombustible materials to coal dust to reduce the risk of explosion (MSHA, n.d.b).

Assumptions

All of the data I have collected and included in this study will be accurate due to the credibility of the sources from which it was gathered. There are unique hazards in the two events under study that must be effectively managed in order to prevent workplace explosions. These hazards are (1) combustible dust in the sugar industry and (2) coal dust and the buildup of methane in the coal industry.

Limitations

Due to the qualitative nature of this research, applicability of the results will be limited to transferable elements that the reader can identify and apply in a given work environment. A large portion of data will be based on official agency reports. Therefore, the accuracy of these reports will also constitute a limitation of my research.

Organization of the Study

My research will be presented in five sections: background, literature review, methodology, research findings and analysis, and discussion and implications. The background discusses the sugar refining and underground mining processes, the problems in these industries, the reason for conducting this research, the significance, limitations, and assumptions of this research, and related terms the reader may need to know. The literature review contains a summary of several references discussing the explosive hazards present in the sugar refining and mining industries. The methodology discusses how I conducted my research, what my research includes, and how I will utilize it. Research findings and analysis explore, in greater detail than the literature review, hazards associated with these industries and accidents directly related to those hazards. The discussion and implications section contains the final analysis of answers to specified research questions.

CHAPTER II

LITERATURE REVIEW

Coal Mining

The underground coal mining environment presents many hazards due to the nature of the mining processes. Methane is a gas that naturally occurs in coal mines due to the formation of coal. During mining practices when the coal is disturbed, methane is released into the air. Several mine explosions have been caused by the accumulation of methane in mines. Skow, Kim, and Deul (1980) state that air in coal mines that contains between a five and 15 percent concentration of methane and no less than 12.1 percent oxygen will explode if ignition occurs. Although methane is not the only explosion hazard present in coal mines, explosions tend to spread more rapidly with the presence of methane in the air. Continuous ventilation of coal mines is the universal solution to ensure methane is kept at safe levels. Skow, Kim, and Deul (1980) discuss the major factors related to coal mine explosions in the younger years of mining. These factors include insufficient ventilations, smoking, failure to keep dust accumulation under control, lack of gas testing, the incorrect use of black powder during blasting, and open light use. Dry coal dust suspended in the air is also an explosive hazard, and when it is combined with high methane concentrated air, explosions are more likely to occur.

During the mining process fine coal dust is dispersed in the air through ventilation and can travel relatively far before settling. This is referred to as float coal dust. Coal dust is extremely explosive and to prevent explosion from occurring, rock dust is spread on the floors, top, and sides of underground mines. According to the

National Institution of Occupational Safety and Health (NIOSH), coal dust on elevated surfaces of a mine is a much more dangerous explosion hazard than coal dust that settles on the floor. Research suggests that when rock dust is the primary dust on elevated surfaces, the potential for explosion is reduced. Float coal dust can be minimized through the reapplication of rock dust, standard cleanup, by mixing underlying rock dust with float coal dust, and by washing down mine surfaces (NIOSH, 2006).

Coal dust is a highly explosive material. As the particle size decreases, coal dust is more likely to be suspended in the air and explosions are more likely to occur. There are five elements that must be present for an explosion to take place, and these five elements are known as the Explosion Pentagon. These five elements are fuel, heat, oxygen, suspension (occurs when particles are dispersed into the air), and confinement. If one of these elements is removed, an explosion cannot occur. Stephan (n.d.) goes on to explain the required characteristics for each element of the Explosion Pentagon.

NIOSH and MSHA joined together to perform a survey that would take dust samples from the intake airways of coal mines in the United States and determine the size range of coal particles found in these samples then compared them to the results of the previous survey of 1920. The amount of rock dust required to reduce coal dust is determined by the size of the coal dust. Smaller coal dust particles require the use of more rock dust. MSHA inspectors collected dust samples from each of their 10 bituminous Coal Mine Safety and Health districts. Sapko, Cashdollar, & Green (2007, p. 616) explain that “the laboratory analysis procedures included acid leaching of the sample to remove the limestone rock dust, sonic sieving to determine the dust size, and low-temperature ashing of the sieved fractions to correct for any remaining incombustible matter.” The results of this experiment show that dust found at mine intake airways contains smaller particles of coal dust than they did in 1920. Therefore, increased amounts of incombustible matter are required to effectively reduce the hazard of coal dust. The current regulation requiring 65 percent incombustible matter would need to be increased (Sapko, Cashdollar, & Green, 2007).

Carbon monoxide (CO) is likely to cause suffocation of miners due to chemical asphyxiation during an explosion. When inhaled, CO makes it difficult for the blood to deliver oxygen to the body’s tissues and the tissue begins to die. According to MSHA (n.d.a) miners are more likely to die from CO exposure than from the burns caused by an explosion. To help prevent over exposure to CO, meters are used to detect CO levels and warn the miners to evacuate should dangerous levels of CO be present (MSHA, n.d.a).

Large drops in barometric pressure during the winter months cause conditions that are more likely to propagate an explosion than warmer weather months. The months of October through March are known to historically have the most devastating mine disasters. Due to these increased dangers, MSHA (1998, para. 4) reminds miners to continue using the four lines of defense: “consistently follow the mine’s approved ventilation plan; conduct thorough pre-shift, on-shift, and weekly checks for methane and other hazards; keep potential ignition sources out of working areas; and complete rock dusting in all areas of the mine.”

Sapko, Weiss, Cashdollar, & Zlochower (n.d.) discuss the testing of dust explosions that took place in the laboratory chamber at the Pittsburgh Research Laboratory (PRL) and the full scale tests that took place at the Lake Lynn experiment mine, both belonging to NIOSH. This research was used to compare laboratory experiments to full-scale mine experiments and observe whether laboratory experiments effectively simulate those that occur in full-scale mines. The results showed similar results in laboratory and mine studies of explosion limits. The purpose of the full-scale mine explosion tests was to determine the explosive resistance of the seals that separate inactive, non-ventilated working areas from the active working areas in mines. The results showed an increase in explosive overpressure due to an increase of coal dust and signs of piled pressure.

Combustible Dust

According to OSHA (n.d.b, para.1) “combustible dusts are fine particles that present an explosion hazard when suspended in air in certain conditions”. To make combustible dust explosive there are four other factors that must be present along with the combustible dust: oxygen, heat, dispersion, and confinement. Even more dangerous than the primary combustible dust explosion is the secondary explosion. The primary explosion may disperse other dormant dust into the air resulting in one (or possibly more) secondary explosions. Because of the increased volume of combustible dust suspended in the air, these secondary explosions can be much more destructive than the initial explosion. Secondary explosions have been the cause of many deaths and other damages in past accidents. To help reduce the risk of combustible dust explosions OSHA recommends a few strategies; inspections, good housekeeping, testing, implementing a dust control program, dust collection systems, ventilation, minimize the escape of dust from equipment and ventilation systems, and minimize dust accumulation on surfaces (OSHA, n.d.b).

Blair (2007) discusses findings from her analysis of a study performed by the U.S. Chemical Safety and Hazard Investigation Board (CSB) on combustible dust explosion and fire hazards. The CSB concluded “that combustible dusts present a serious safety hazard in general industry.” Through her analysis, Blair found that over the past 25 years there have been close to 300 incidents that resulted in 119 fatalities and 723 injuries. In many of these tragedies, employees were unaware of the combustible dust hazards. She determined that neither the OSHA Hazard Communication nor the American National Standards Institute (ANSI) Material Safety Data Sheet (MSDS) standards addressed the combustible dust hazard, and no OSHA standard currently published addresses the issue in general industry, with the exception of the grain industry. The National Fire Prevention Association (NFPA) standards do have a detailed recommendation for preventing and mitigating dust explosions and fires, but unless adopted by state or local fire codes, these standards are only voluntary. Because of the findings from this study, CSB recommended that OSHA develop and implement a new standard for combustible dust, communicate the hazards of combustible dust, and specify requirements for combustible dust under the Hazard Communication standard (Blair, 2007).

Joseph (2006) also conducted an analysis of the CSB combustible dust explosion and fire study and concluded the same findings. He found that combustible dust is a serious industrial hazard and that hundreds of incidents over the past 25 years have resulted in numerous deaths, injuries, and loss of business. He found that there is a general lack of awareness and general regulatory standards that address combustible dust and that MSDSs do not cover combustible dust hazards.

To allow readers a better understanding of dust explosion fundamentals, Cashdollar (2000) conducted research that provides information regarding the ignitability and explosive properties of dust clouds “that can be used to improve safety in industries that generate, process, use, or transport combustible dusts” (p. 183). He found that dust explosion characteristics can be studied using laboratory test chambers. He also concluded that finer sized particles of dust constitute a larger hazard than large particles and that “the effects of the initial system temperature, pressure, and oxygen concentration” should be considered to determine explosion characteristics (Cashdollar, 2000, p.197).

Eckhoff (1996) summarized his research of publications dated 1990 and later to provide a distinctive increased knowledge of dust explosion prevention and mitigation. He concluded that the occurrence of industrial dust explosions are in fact a very intricate occurrence and predicting such a phenomenon using chemical and physical principles was not possible. The current knowledge base of dust explosions is incomplete, but eventually all of the pieces will be put together and become lucid. Until that time, industrial-scale experiments should continue to be conducted.

CHAPTER III

METHODOLOGY

Context of Study

The context of this study is to evaluate the Sago mine explosion of 2006 and the Imperial Sugar refinery explosion of 2008. The Sago mine explosion of 2006 occurred on January 2 at the Wolf Run Mining Company's Sago mine in West Virginia. This particular mine was an underground bituminous coal mine. On the day of the explosion 29 miners entered the mine and, due to rescue difficulty after the explosion, only 17 miners survived.

On February 7, 2008 one of Imperial Sugar's sugar refineries exploded leaving 14 of 135 employees present with fatal injuries. The refinery is located in Port Wentworth, Georgia on the banks of the Savannah River. The Port Wentworth refinery converts raw cane sugar into granulated sugar.

Interpretivism is the theoretical framework that was utilized for this research in that "problems and the research questions explored aim to understand specific issues or topics" (Creswell, 2007, p. 24). Interpretivism helps to inform our understanding of the lens through which MSHA and OSHA view incidents and make meaning of what is seen, particularly in the area of workplace explosions as addressed within the scope of this research. My research questions were designed to gain an understanding of how MSHA and OSHA respond to the problem of workplace safety explosions and how they interpret the issues involved within the scope of their respective jurisdictions.

Research Questions

The questions this research seeks to answer are:

1. What are the explosive hazards present in the coal mining and sugar refining environments?
2. What explosion prevention methodologies are available?
3. What MSHA regulations apply to coal mine explosions and what OSHA regulations apply to refinery explosions?
4. Are there differences in the way that the agencies enforce regulations when faced with a similar catastrophic event?

Data Collection

The archival documents I reviewed are the following:

1. Mine Safety and Health Administration publications
2. Mine Safety and Health Administration regulations
3. Occupational Safety and Health Administration publications
4. Occupational Safety and Health Administration regulations
5. National Institute of Occupational Safety and Health publications
6. Journal articles
7. Official Report of Investigation of the 2006 Sago mine explosion
8. U.S. Chemical Safety and Hazard Investigation Board Investigation Report of the 2008 Imperial Sugar refinery explosion
9. News reports

Data Analysis

The information gained from a review of the archival resources will be evaluated to identify themes (Creswell, 2007). Themes are created as a result of analyzing data which is in the form of:

1. Topical information found in regulations
2. Topical information found in incident reports
3. Topical information found in journal articles
4. Information from citations and fines

Subjectivities

As a safety professional I feel as though OSHA does not enforce regulations as they should, nor do they inspect facilities as often as they should. I believe that I effectively manage safety at my facilities, but sometimes issues are hidden and therefore I feel that I need to be aware of all potential risks. This awareness will allow me to protect employees, myself, and the company I work for from experiencing such disastrous events as explosions. In order to ensure these subjectivities do not appear in my paper I have remained focused on the facts that I researched from credible sources and only analyze the researched data.

CHAPTER IV

RESEARCH FINDINGS AND ANALYSIS

Explosion Pentagon

In order for an explosion to occur, five elements must be present. These elements are fuel, heat, oxygen, suspension, and confinement. When these five elements are present it is known as the Explosion Pentagon and an explosion will occur. If you take one of these elements away an explosion is no longer possible (Stephan, n.d.).

Fuel Sources

Methane. Methane in coal mines is a dangerous explosive hazard and is released into the air due to typical mining processes. Methane is odorless, colorless, nonpoisonous, and lighter than air, making it near impossible to detect without monitoring equipment. Mine air that contains at least 12.1 percent oxygen and between 5 and 15 percent methane will explode if ignition occurs. Methane is not the only explosive hazard in mines; coal dust that is suspended in air is also an explosive hazard. However, coal dust explosions are likely to occur more quickly and more readily with the presence of methane (Skow, Kim, & Deul, 1980). Between the months of October and March, cold weather increases the chance of a methane explosion. Dramatic decreases in barometric pressure allow methane to move from inactive areas of the mine to travel ways and active work areas. This increases the chance of an explosion because the explosive mixture of methane and air is more likely to come into contact with an ignition source in these areas (MSHA, 1998). Several geologic features, such as faults, are notorious for housing large quantities of methane gas. Because of this when strata located adjacent to coal beds are disturbed, unusually high levels of methane are released causing explosive hazards (Ulery, 2008).

Coal Dust. In order for coal to be explosive, coal must possess certain measurements for volatile ratio, particle size, and minimum explosive concentration (MEC). The volatile ration of the coal must be greater than 0.12 to be considered an explosive hazard. Stephan (n.d, p. 2) defines volatile ratio as “the volatile matter divided by the summation of volatile matter and fixed carbon of the coal.” As particle size of coal dust decreases, its explosive hazards increase. Smaller dust particles ignite with lower temperatures and less energy than larger particles. Coal dust particles must be 0.03 inch or smaller to cause an explosion. The MEC is “the minimum quantity of dust in suspension that will propagate a coal dust explosion and generate sufficient pressure to cause damage” (p.3). The MEC for bituminous coal is approximately 0.10 ounce per cubic foot. A common rule for coal dust is that if enough dust accumulates on the floor and footprints can be seen, or dust is visible on the walls of the mine, then there is a large enough quantity of dust in that area to cause an explosion (Stephan, n.d.).

During cold weather months, October through March, the risk of a coal dust explosion is much higher. Cool, dry air from outside the mine enters the mine and pulls out moisture from working areas. As the moisture is removed from coal dust it is more difficult to control and becomes suspended in the air causing an increase in explosion hazards (MSHA, 1998).

Combustible Dust. OSHA defines combustible dust as "a combustible particle solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape" (OSHA, 2008, para. 20). Smaller dust particles have more exposed surface areas causing them to combust faster than larger particles (OSHA, 2010a). Sugar dust can have a very low minimum ignition energy (MIE) of four millijoules, is non-conductive, and the explosion of finer particles can cause rapid pressure increases (Jeffries, 2010). When discussing the ignitability of combustible dusts, *The Dust Hazard in Industry*, a 1925 publication, stated that

> "sugar, dextrin, starch, and cocoa are the most dangerous, sugar exceptionally so. Sugar ignites when projected as a cloud against a surface heated to below red heat, and when ignition has taken place, the flame travels throughout the dust cloud with great rapidity" (CSB, 2009, p. 22).

The accumulation of combustible dust on horizontal surfaces is not an explosion hazard in itself. The hazard becomes present when the dust is suspended in the air and mixed with a concentration of oxygen greater than the lower explosive limit and lower than the upper explosive limit. Areas of combustible dust accumulation as little as 1/32 inch deep that cover no less than five percent of floor areas are considered by the NFPA to be a substantial explosive hazard (Geddie, n.d).

Controlling Fuel Sources.

To control the levels of methane in the air, mines continuously operate mechanical fans to ventilate working areas of the mine. Currently ventilation is the only technique that is universally implemented for maintaining safe levels of methane in underground mines (Skow, Kim, & Deul, 1980). Through ventilation, working faces of the mine are constantly supplied with fresh air to prevent the explosive mixture of oxygen and methane (Ulery, 2008).

Rock dusting is currently the only means of protection used to prevent coal dust explosions in U.S. underground mines (NIOSH, 2006). Rock dust is a combination of incombustible materials that, when moistened and then dried, will form a cake-like coating that will not disperse into the air due to ventilation and other bursts of air. When applied generously, rock dust can eliminate the explosive hazards of coal dust (MSHA, n.d.b). When coal dust is not mixed thoroughly with rock dust and accumulates on top of the rock dust, it creates a highly explosive risk (NIOSH, 2006). Rock dust, when applied liberally and properly maintained in bituminous coal mines, can reduce the risk of causing a widespread, disastrous explosion (MSHA, n.d.b).

There are many practices that when used together can effectively control the accumulation of sugar dust and reduce or eliminate the risk of explosion due to combustible sugar dust. The following are some recommended best practices: conduct routine inspections of areas where sugar dust can accumulate; minimize the release of sugar dust from ventilation systems and processing equipment; ensure employees perform regular cleaning of work areas and participate in continuous housekeeping practices; use dust filters and collection systems; develop and implement a written sugar dust inspection, housekeeping, and control plan (Geddie, n.d); implement the use of dust collectors (OSHA, 2008); use proper ventilation design for process equipment; develop and implement a preventive maintenance program (OSHA, 2010a); consider the use of dense phase conveying (Earls, 2010); and design conveyors to prevent the release of combustible dust (NFPA, 2006). All of these practices allow for the control, limitation, and/or elimination of sugar dust accumulation, therein reducing the risk of a combustible sugar dust explosion (OSHA, 2010a).

Heat Sources

In underground mines, heat can come in the form of energy or temperature. An explosion can occur from the heat sources of frictional or electrical sparks (Stephan, n.d.). Occasionally unplanned and extremely high emissions of dust and/or methane are met, and regardless of typical ventilation methods, sparks from electrical equipment or cutting bits can cause an explosive mixture that can easily be ignited (Ulery, 2008).

Organic matter such as sugar has a considerably low heat of combustion at four kcal/g (kilocalorie per gram) (Jeffries, 2010). The minimum ignition temperature (MIT) of sugar is 680ºF to 788ºF. In the sugar refining industry, heat sources range from sparks and open flames, to static electricity, to hot surfaces and overheated equipment and parts, and even flames from a primary explosion. It is thought that an overheated bearing was the ignition source for the explosion that rocked the Imperial Sugar Refinery in 2008 (CSB, 2009). Monitoring can be used to prevent some of these heat sources from becoming an ignition hazard.

Bearing monitors can be used to monitor the temperature and condition of bearings and sound an alarm if they become too hot. Alignment and speed monitors can be used to ensure that conveying belts and other belts remain aligned and at an acceptable speed to prevent heat caused by the friction of a belt rubbing against another piece of equipment (OSHA 2002; CSB, 2009). Temperature monitors can be placed on bearings to detect overheating. Alignment, speed, and temperature monitors will activate an alarm or shut down equipment in the event of dangerous conditions (OSHA, 2002). Another way to prevent some of these potential ignition hazards is to ensure there are no combustible dust hazards in an area where hot work, such as cutting or welding, is being performed or where smoking is permitted (NFPA, 2006).

Oxygen

"Concentrations of oxygen in excess of its concentration in air increase most combustion hazards to a degree directly related to the concentration, which affects all basic combustion parameters, except for the heat of combustion" (National Fire Protection Agency, 2008, p. 6-185). When increases in coal's volatile content occur the completion of the explosion pentagon requires less oxygen. In the presence of a strong ignition source and ambient temperatures, a reduction of oxygen content to below 13 percent must occur in order to prevent bituminous coal dust explosions (Stephan, n.d.). As for methane, air that contains between 5 and 15 percent methane and no less than 12.1 percent oxygen will explode when ignited (Skow, Kim, & Deul, 1980).

The explosive range of an oxygen and combustible dust mixture in the air is between the upper explosive limit and lower explosive limit. A concentration above or below these limits will not cause an explosive hazard. This can be done by preventing air intake, causing a large decrease in the amount of oxygen present.

However, this would not be acceptable in areas occupied by human workers. Another option would be to excessively dilute the combustible dust with air (Bartec, n.d).

Suspension

Suspension is necessary to complete the explosion pentagon. The explosive dangers of suspended coal dust are extreme because, once the particles are suspended, they typically only need to find a heat source to cause an explosion. Heat to complete the explosion pentagon can sometimes be present when coal dust on the floor of the mine reaches smoldering temperatures and an explosion can occur when the coal dust is then somehow positioned into suspension (Stephan, n.d.).

Suspension of combustible dust, such as sugar, is dependent on the size of the dust particles. The smaller the dust particle, the easier it is suspended in the air. In order for combustible dust to be suspended there must be an investment of energy to disperse the dust particles into the air. According to OSHA (2010a, p.399), “some sources of suspension are moving air, pneumatic conveying, mechanical conveying, pouring, acoustic impulses, other deflagrations, mechanical impact and vibrations.” The blast from a primary explosion can also cause accumulated combustible dust particles to be suspended in the air (Geddie, n.d).

Confinement

Without the close proximity of particles, heat cannot travel quickly enough to allow continuous spreading of an explosion. Therefore, the propagation of an explosion is not possible without confinement. Instead, a large fireball would be produced with no forces to combine with it to cause an explosion (Stephan, n.d.).

According to OSHA “confinement can be any enclosure (2009, p. 54,335).” In a refinery, sources of confinement include caged/covered equipment, closed-off rooms and areas, individual buildings, ducts, processing equipment, a room, storage equipment, and storage facilities such as silos (National Archives and Records Administration, 2009). For example, an unventilated enclosed conveyor belt where sugar dust can accumulate would be a source of confinement (CSB, 2009).

Carbon Monoxide

Carbon Monoxide gas (CO) is known to most miners as white damp or the silent killer because of its odorless, tasteless, and colorless nature. CO is emitted through the incomplete combustion of materials, such as coal, that contain carbon. When miners inhale CO it enters their blood stream and interferes with the body’s ability to transfer oxygen through the blood stream to vital tissue. The lack of oxygen to tissue caused by CO inhalation begins to kill the tissue and eventually the miner. High levels of CO are produced during mine explosions making evacuations and rescues dangerous. Miners and rescue team members need to pay special attention to CO levels. During a mine explosion, miners are more likely to die of chemical asphyxiation from CO poisoning than from the burns the explosion causes (MSHA, n.d.a).

Mine Safety and Health Administration Regulations

> “The mission of the Mine Health and Safety Administration (MSHA) is to administer the provisions of the Federal Mine Safety and Health Act of 1977 (Mine Act), as amended by the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), and to enforce compliance with

mandatory safety and health standards as a means to eliminate fatal accidents; to reduce the frequency and severity of nonfatal accidents; to minimize health hazards; and to promote improved safety and health conditions in the Nation's mines" (MSHA, n.d.c, para. 1).

MSHA regulations are grouped in 30 CFR (Code of Federal Regulations), Parts 1 through 199. MSHA 30 CFR regulations are divided into ten subchapters lettered A through Q. These subchapters are then divided into parts numbered 1 through 199, parts are divided into lettered subparts, and subparts are divided into numbered sections. For example, 30 CFR subchapter H part 49 is divided into subparts A and B which are divided into 23 sections. Therefore, section eight of 30 CFR 49 subpart B would read 30 CFR 49.8, where 49 is the part and eight is the section.

According to 30 CFR 48, all new miners must receive at least 40 hours of safety training before working in an underground mine. Eight of these training hours must be given on the mine-site, while the other 32 hours must attempt to mimic the actual underground environment as closely as possible. For training to be in compliance with MSHA, training of new miners must consist of the following courses: (1) instruction in the statutory rights of miners and their representatives under the Act; (2) self-rescue and respiratory devices; (3) entering and leaving the mine, transportation, communications; (4) introduction to the work environment; (5) mine map, escape ways, emergency evacuation, barricading; (6) roof or ground control and ventilation plans; (7) health; (8) cleanup, rock dusting; (9) hazard recognition; (10) electrical hazards; (11) first aid; (12) mine gases; (13) health and safety features of the tasks assigned to the new miner; and (14) any other course, due to circumstances and conditions, required by the District Manager.

In accordance with 30 CFR 48.8, all miners are required to have a minimum of eight hours refresher training annually. Annual refresher training must consist of the following courses: (1) mandatory health and safety standards; (2) transportation controls and communication systems; (3) barricading; (4) roof or ground control, ventilation, emergency evacuation, firefighting plans; (5) first aid; (6) electrical hazards; (7) prevention of accidents; (8) self-rescue and respiratory devices; (9) explosives; (10) mine gases; (11) health; and (12) any other courses deemed necessary by the District Manager due to conditions and circumstances.

All mine rescue team members (in accordance with 30 CFR 49.17), must have an annual physical to ensure members are physically capable of handling rescue duties. When performing a physical, physicians must consider the following conditions to ensure a rescue member's physical fitness: seizure disorder, perforated eardrum, hearing loss, high blood pressure, poor vision, heart disease, hernia, absence of limb or hand, and any other condition that may prevent a rescuer from performing their duties. A team member that requires eyeglasses will not be disqualified as long as the eyeglasses can be securely worn in an approved face piece.

Individuals interested in becoming a member of a mine rescue team must complete a minimum of 20 hours of initial training before serving on a team. The initial training course will instruct members how to care for, use, and maintain breathing apparatus that would be used during a rescue. The training must be performed as required by the Mine Health and Safety Administration's (MSHA) office of Educational Policy and Development (30 CFR 49.18).

After completion of initial training, members must receive a minimum of 96 hours of annual refresher training. This training must be given for at least eight hours every two months. During annual refresher training, team members learn about and practice rescuing techniques and learn how to use rescuing equipment.

Methane is monitored and mines are ventilated to help prevent mine explosions and respiratory problems. According to 30 CFR 75.323, if methane levels in a work place reach one percent or greater, all electronically powered equipment, except for intrinsically safe atmospheric monitoring systems (AMS), must be de-energized and shutdown. Ventilations systems must also be changed or adjusted until the methane level falls below one percent, and all work in the affected area must stop. When levels of methane in an underground coal mine reach one and a half percent or above, all employees, except authorized personnel, must evacuate the area and all electronically powered equipment must be de-energized and shutdown, with the exception of intrinsically safe AMS.

Rock dusting is used to help prevent the suspension of coal dust in the air, which decreases the risk of explosion due to coal dust. 30 CFR 75.402 requires that all areas of an underground coal mine, except areas of high moisture and high incombustible content, must be rock dusted to within 40 feet of all working faces. However, if an area is inaccessible or unsafe to enter, rock dusting is not required.

Occupational Safety and Health Administration Regulations

According to OSHA their mission is stated as follows:

"With the Occupational Safety and Health Act of 1970, congress created the Occupational Safety and Health Administration (OSHA) to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education, and assistance" (OSHA, n.d.a, para. 1).

OSHA standards are grouped in 29 CFR parts 24 through 2400. These parts are then divided into lettered subparts and the subparts are divided into numbered sections. For example, 29 CFR part 1910 subpart D is divided into sections 21 through 30. Therefore, section 23 of 29 CFR part 1910 subpart D is written as 29 CFR 1910.23 (OSHA, n.d.c). For the purpose of this research 29 CFR part 1910, OSHA's General Industry Standards, will be used.

Currently OSHA does not have a standard to regulate emergency response/rescue teams in the event of an explosion. OSHA's Medical Services and First Aid standard, 29 CFR 1910.151, only requires emergency personnel on site when other medical facilities are not within close proximity to the employer's facility. OSHA's Maritime First Aid and Lifesaving Facilities standard, 29 CFR 1917.26 requires a first aid certified personnel be on site when any work is being performed, but this standard only regulates unique water related hazards and emergencies making it not directly applicable to explosion hazards. The only OSHA standard containing guidelines for response/rescue teams is 29 CFR 1910.146, OSHA's Confined Space Entry standard. However, this standard only applies to emergency situations involving entry into permit required confined spaces and does not address incidences such as explosions in general industry.

OSHA does not currently have a standard to regulate combustible dust in all industries. OSHA standards such as the OSHA housekeeping standard and electrical standard address some, but not all of, the risks associated with combustible dust. The General Duty Clause is currently being used to cite facilities with combustible dust hazards (National Archives and Records Administration, 2009).

In the 1970s OSHA began to develop a combustible dust standard for the grain handling industry due to several devastating explosions. The final standard was not published until December 31, 1987 (National Archives and Records Administration, 2009). The grain handling standard, 29 CFR 1910.272, has proven to be effective in preventing the occurrence of combustible dust explosions by cutting these deaths and injuries by 60 percent (CSB, 2009). The grain handling standard regulates issues that include, but are not limited to, housekeeping, hot work, ventilation, preventive maintenance, and equipment monitoring and design (OSHA, 2002).

In an attempt for employers to better understand combustible dust hazards, OSHA published a Safety and Health Information Bulletin in 2003 titled *Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosion* in response to a series of incidents (National Archives and Records Administration, 2009). This bulletin served as a general guide to industry employers for the control of combustible dust hazards (CSB, 2009).

A Combustible Dust National Emphasis Program (NEP) was developed by OSHA in October 2007 to assist OSHA inspectors in better citing combustible dust hazards in facilities. The NEP is a written guide for inspectors to help them apply "The General Dusty Clause and existing standards, such as walking working surfaces standard, to conditions and practices that impact or are related to combustible dust hazards." However, "it does not establish a new enforceable combustible dust hazards standard" (CSB, 2009, p. 55-56).

Sago Mine Explosion of 2006

At 6:26 am on January 2, 2006, an explosion occurred in the 2 North Main seals at West Virginia's Wolf Run Mining Company's Sago mine. That morning 29 miners entered the mine heading for the 1st Left Parallel and the 2nd Left Parallel (see Appendix A for map of Sago mine). After the explosion, one man died of carbon monoxide poisoning and the others attempted to evacuate the mine. The crew in the 1st Left Parallel successfully evacuated, but the 2nd Left Parallel crew's evacuation was not as successful. The 2nd Left Parallel crew barricaded themselves on the 2nd Left Parallel section and waited to be rescued. The explosion had destroyed all the seals that separated an inactive area of the mine from the working areas. Management reentered the mine to assess the situation. They discovered that the explosion had destroyed the ventilation controls. They attempted to restore ventilation by using temporary controls so they could reach the trapped miners. They were unable to eliminate the gases and smoke, and eventually retreated from the mine and ended their rescue attempt. After state and federal agencies arrived, rescue teams were established and rescue efforts began. However, due to high levels of carbon monoxide and methane, the rescue was delayed. After the gas concentration stabilized, rescue teams began entering the mine. On January 3 rescue teams found the first victim close to the 2nd Left Parallel track switch. Later that evening rescue teams advanced to the 2nd Left Parallel and found 12 miners behind a barricade. Only one miner had survived and the other 11 had perished due to carbon monoxide poisoning. The surviving minor was rescued and taken to the hospital. The remaining 11 victims were finally recovered from the mine on January 4, two days after the explosion (MSHA, 2007b).

Investigators found that methane gas had accumulated in a previously mined area that had been sealed off. When the explosion occurred in the sealed area, it destroyed the seals. This resulted in the release of toxic levels of carbon monoxide in areas of the mine. The explosion is thought to have caused pressures exceeding 93psi; regulations only require seals to withstand 20psi. Investigators concluded that coal dust did not cause the explosion, and there was no evidence suggesting that welding, cutting, smoking, spontaneous combustion, or mining operations contributed to the ignition. Equipment and electric systems were also not considered to be potential ignition sources. As highly unlikely an ignition source as it is, roof collapse was not ignored as a potential source of ignition (MSHA, 2007b).

Around the same time the mine explosion occurred, several lightning strikes were reported near the mine. MSHA contracted with Sandia Corporation, Sandia National Laboratories' operator, to determine whether lightning could have caused electrical energy to stream through the mine and cause an explosion. Sandia concluded that lightning could in fact create the right amount of energy to create an arc in the sealed area. It has been determined that lightning is the most likely ignition source for the Sago mine explosion (MSHA, 2007b).

The lightning strike caused energy to transfer onto a pump cable that had been abandoned in the sealed area of the mine. This caused the ignition of accumulated methane in the sealed area (MSHA, 2007b). According to the Report of Investigation,

> "a methane explosion initially occurred in the 2nd Left Main in the general area of the survey stations 4010 in the No. 6 entry and 4011 in the No. 7 entry. These survey stations were located in the No. 2 Crosscut. As the flame from this explosion expanded, it began to propagate through explosive concentrations of methane in all directions" (MSHA, 2007b, p. 184).

Investigators determined three root causes for the Sago mine disaster of 2006. The first root cause was the inability of the seals to withstand the pressure that was initiated from the explosion. The second cause was the lack of monitoring of the atmosphere in the sealed areas which contained explosive air and methane mixtures. Lastly, as previously mentioned, lightning was the most likely source of ignition (MSHA, 2007b).

There were no contributory citations given to the mine operators following the accident investigation. However, several significant actions were addressed: the seals at the 2 North Mains were not built in compliance with MSHA regulations, immediate notification of the accident was not given to MSHA or mine rescue teams, and lightning arresters where not on five electrical circuits entering/exiting the mine. As a result of the investigation, 149 non-contributory citations, or orders, were given out. Most (117) were issued prior to the inspection report, and 32 were issued with the report (MSHA, 2007b).

Due to the Sago mine explosion of 2006, MSHA is increasing strength requirements of seals from 20psi (pounds per square inch) to 50psi. MSHA contracted with Sandia National Laboratories to conduct tests that would allow them to determine whether underground travel of energy from a lightning strike could have caused the explosion. MSHA concluded that the cause of the explosion was a lightning strike that exerted about 93psi of pressure at the seals, which could only withstand 20psi, causing them to blow (MSHA, 2007a).

Following the Sago mine explosion, MSHA issued an Emergency Temporary Standard known as the Emergency Mine Evacuation Rule on March 9, 2006. The Final Rule for Emergency Mine Evacuations was instated on December 8, 2006 with the following requirements: "prompt incident notification, mandatory lifelines in mines, training, increased quantities of Self-Contained Self-Rescue (SCSR) devices, and for mine operators to report updated SCSR inventory on a quarterly basis (MSHA, 2007c, p. 138)."

In February 2007 MSHA addressed the MINER Act requirement for providing trapped miners with breathable air in a Program Information Bulletin (PIB). MSHA published a final rule in March 2007 that became effective in April 2007. This rule changed MSHA's current civil penalty assessment regulations and "codified MINER Act provisions establishing the maximum penalty for flagrant violations and minimum penalties for unwarrantable failures and immediate notifications rule violations". The hope was that these higher penalties would motivate mine operators to be more proactive in preventing and correcting violations and ensuring a safer work environment (MSHA, 2007c, p. 138).

MSHA instated an Emergency Temporary Standard on Sealing of Abandoned Areas in May 2007. "The standard includes requirements to strengthen the design, construction, maintenance, and repair of seals, as well as requirements for sampling and controlling atmospheres behind seals (MSHA, 2007c, p. 139)". In order to prevent or withstand overpressure-loading, the standard implements a three-tiered approach for the construction of new seals:

> "(1) Seals may be constructed to withstand 50psi, but the atmospheres behind them must be monitored and maintained inert. (2) If the atmosphere is not monitored and maintained inert, the seals must be constructed to withstand 120psi. (3) Where higher explosion pressures are possible within sealed areas that are not monitored and maintained inert, the seals must be constructed to withstand more than 120psi" (MSHA, 2007c, p. 139).

As of October 20, 2008 all mining operations must comply with the Seal Strengths, Design Applications, and Installations Standard, 30 CFR 75.335 (MSHA, n.d.e).

Imperial Sugar Refinery Explosion of 2008

In February 2008 it became apparent that sugar was a combustible dust when the Imperial Sugar refinery in Georgia "suddenly and violently exploded" (Clark, n.d, para. 4). It is believed the explosion was caused by the ignition of accumulated sugar dust in the refinery. According to John Oxendine, the Georgia Fire Commissioner, the blast was "the worst industrial accident" of his 14 year tenure (Clark, n.d, para. 4). The explosion was said to be massive and destroyed whole sections of the refinery causing the framework and foundation of the facility to be exposed (see Appendix B for maps of Imperial refinery).

At approximately 7:15 pm on February 7, 2008, the Imperial Sugar refinery in Port Wentworth, GA was devastated by a series of explosions caused by sugar dust. Due to this disastrous blast, 14 employees were killed and 36 were seriously injured. Of these employees, two reentered the building in an attempt to rescue but never made it out, four were trapped by falling debris and collapsing floors, eight died on the scene, and six died later. The last burn victim died six months after the explosion. By the time the emergency crews and fire department arrived, employees had already begun search and rescue attempts and those injured were being transported to the main gatehouse.

According to the U.S. Chemical Safety and Hazardous Investigation Board (CSB), the initial explosion began when an unknown source ignited the sugar dust in an enclosed steel belt conveyor below the sugar silos. The newly installed steel cover panels allowed for a large and highly explosive accumulation of sugar dust in the enclosed equipment. This initial explosion dispersed more sugar dust that had accumulated on the floor and other surface into the air causing multiple explosions to spread throughout the other buildings.

The secondary explosions ripped through areas of the refinery, bulk sugar loading buildings, and the packing buildings. The bulk sugar loading area and parts of the refinery were severely damaged and the packing building, palletizer buildings, and silos were destroyed by the fires that resulted from the explosions. Most of the fires were extinguished by the following day, but smaller fires continued to burn for several days following the explosion. The fires in the silos burned for seven days before they were finally extinguished. CSB concluded that the incident resulted from improper design or maintenance of equipment, insufficient housekeeping practices, and an accumulation of airborne combustible sugar dust had exceeded the minimum explosive concentration. The initial ignition source was most likely an overheated bearing, the initial explosion caused the secondary explosions and fires, and the secondary explosions and fires were most likely what lead to the 14 employee fatalities at Imperial Sugar (CSB, 2009).

As a result of the explosion at their Port Wentworth facility, Imperial Sugar was fined $4,050,000 for 124 cited violations. Of these violations 51 were cited as serious, 69 as willful, and four as other (OSHA, n.d.d). The citations claimed that Imperial Sugar neglected to address combustible dust hazards (OSHA, 2010b). CSB described the incident as "entirely preventable" and cited poor equipment design, housekeeping, and maintenance as the reasons for this tragic incident (Earls, 2010). Of these 124 violations the following 28 standards were cited:

1. General Duty Clause
2. 29 CFR 1910.22 – General Requirements
3. 29 CFR 1910.23 – Guarding floor and wall openings and holes
4. 29 CFR 1910.24 – Fixed industrial stairs
5. 29 CFR 1910.27 – Fixed ladders
6. 29 CFR 1910.36 – Design and construction requirements for exit routes
7. 29 CFR 1910.37 – Maintenance, safeguards, and operational features for exit routes

8. 29 CFR 1910.68 – Manlifts
9. 29 CFR 1910.146 – Permit-required confined space
10. 29 CFR 1910.147 – The control of hazardous energy (lockout/tagout)
11. 29 CFR 1910.157 – Portable fire extinguishers
12. 29 CFR 1910.178 – Powered industrial trucks
13. 29 CFR 1910.212 – General requirements for all machines
14. 29 CFR 1910.215 – Abrasive wheel machinery
15. 29 CFR 1910.219 – Mechanical power-transmission apparatus
16. 29 CFR 1910.243 – Guarding of portable powered tools
17. 29 CFR 1910.254 – Arc welding and cutting
18. 29 CFR 1910.303 – General requirements
19. 29 CFR 1910.305 – Wiring methods, components, and equipment for general use
20. 29 CFR 1910.307 – Hazardous (classified) locations
21. 29 CFR 1910.334 – Use of equipment
22. 29 CFR 1910.1025 – Lead
23. 29 CFR 1910.1200 – Hazardous Communication
24. 29 CFR 1917.26 – First aid and lifesaving facilities
25. 29 CFR 1917.48 – Conveyors
26. 29 CFR 1917.111 – Maintenance and load limits
27. 29 CFR 1917.112 – Guarding of edges
28. 29 CFR 1917.151 – Machine guarding

Following the Imperial Sugar explosion, OSHA reissued its Combustible Dust NEP in March 2008 and stated that it was going to begin stricter enforcement for combustible dust hazards as part of their amendment of the NEP (OSHA, 2008). The Combustible Dust NEP was revised to "focus on industries with more frequent and high consequence dust incidents, and to include more inspections" (OSHA, 2009, para. 4). The new revision targeted 64 industries including sugar refineries. Due to the increased number of inspections, OSHA discovered that only 18 to 22 percent of the inspected facilities were in compliance with OSHA requirements (OSHA 2009).

In July 2008 OSHA announced its intentions to revise the housekeeping standard to "more explicitly state what had always been true: that the standard applied to accumulations of dust that contribute to an explosion hazard" (CSB, 2009, p. 55). Until that time, OSHA continues to use the combustible dust NEP. In April 2009, 14 months following the Imperial Sugar refinery explosion, OSHA announced their intentions of developing a general industry combustible dust standard (CSB, 2009).

Due to the explosion and resulting violations, OSHA will be working with Imperial Sugar to ensure health and safety becomes a top priority for the company. According to the Secretary of Labor, Hilda L. Solis, "this agreement requires Imperial Sugar to make extensive changes to its safety practices and it underscores the importance of proactively addressing workplace safety and health hazards" (OSHA, 2010b, para. 2). At their request OSHA will now be receiving accurate and current copies of Imperial Sugar's injury logs and have the right to enter and inspect the facility based on these logs without interference from the company. "OSHA will regularly monitor progress and compliance with the agreement and continue to conduct regular inspections of the facility" (OSHA, 2010b, para. 6).

CHAPTER V

DISCUSSION AND IMPLICATIONS

Given the circumstances both explosions can be seen as completely preventable and yet both can also be blamed on factors unrelated to company safety procedures. The closed off area of the Sago mine should have been monitored due to the presence of pump equipment, but the lightning was a natural and unexpected ignitions source and the seals blew out at 93psi and MSHA only required a seal strength of 20psi. Imperial Sugar could have better controlled their accumulation of combustible dust. Although OSHA has language pertaining to combustible dust hazards in several regulations, OSHA did not have a specific standard requiring them to control combustible dust.

My first research question asked, “What are the explosive hazards present in the coal mining and sugar refining environments?” As a result of my findings I have concluded that, though prevention methodologies differ slightly, both mines and sugar refineries are at risk for combustible dust explosions. In mines fine coal dust and methane are dangerous explosion hazards and when mixed together create an even greater risk of explosion. Sugar dust is a major explosive hazard in a sugar refinery, especially when large amounts of sugar dust accumulate in other areas of the facility making secondary explosions plausible.

My second research question asked, “What explosion prevention methodologies are available?” As a result of my findings I have determined the control of explosion hazards in the mining and refining industries vary greatly, but have the same common goal, which is to prevent a devastating explosion from occurring. In order to control the concentration of methane in the air, mechanical fans are used to continuously ventilate the mine. In refineries, ventilation systems are used to supply a sufficient amount of oxygen into the air and dust collectors are used to control the amount of suspended sugar dust. Some type of monitoring is used in both industries to ensure a safe work environment. Mines monitor the level of methane in the air while refineries monitor belt speed and alignment and the temperature of equipment and parts. Regardless of the type of monitoring being used, the monitors serve as an important protective device to warn workers of unsafe conditions.

Combustible coal dust and sugar dust are both extremely explosive hazards, but are controlled in different manners. The most common way to control coal dust is by rock dusting which requires the addition of a noncombustible rock dust. Sugar dust, however, is typically controlled through routine housekeeping which requires the cleanup and removal of sugar dust. The methods for controlling these combustible dusts are completely different, but work best for the specific hazard.

My third research question asked, “What MSHA regulations apply to coal mine explosions and what OSHA regulations apply to refinery explosions?” As a result of my findings I have concluded that MSHA has stringent regulations regarding the training of employees, training of rescue teams, monitoring of methane, ventilation of mines, and rock dusting. All new miners are required to have at a minimum of 40 hours of initial safety training before they are allowed to enter a mine. Each miner is then required to have at least eight hours of annual refresher training. OSHA currently does not have any regulation addressing general safety training to new employees or annual refresher training thereafter that are specifically related to the threat of explosions. MSHA standards regulate the monitoring of methane, application of rock dust, and ventilation of mines to mitigate explosion hazards; however, OSHA currently has no standard addressing combustible dust explosion hazards for general industry.

MSHA regulations require the training and establishment of a mine response and rescue team in the event of emergencies such as explosions. MSHA requires that all mines establish a rescue team, and that all rescue team members have an annual physical and at least 20 hours of initial training and 96 hours of annual refresher training. The only OSHA regulation that resembles the MSHA standard is within the confined space standard but does not regulate general emergencies. The OSHA Medical Services and First Aid standard only requires trained emergency personnel if the facility is not located within close proximity to other medical facilities. Though OSHA cited Imperial Sugar for 29 CFR 1917.26, OSHA's Maritime First Aid and Lifesaving Facilities standard, this standard only addresses unique water related hazards and emergencies making it not directly applicable to explosions.

My fourth research question asked, "Are there differences in the way that the agencies enforce regulations when faced with similar catastrophic events?" As a result of my findings I have concluded that both the Sago Mine explosion and Imperial Sugar Refinery explosion were exhaustively investigated by qualified personnel. MSHA performed their own investigation while the CSB conducted the Imperial Sugar investigation. Having the CSB conduct the investigation along with OSHA may have given an unbiased and fresh look at the hazards that led to the explosion. Investigators with years of experience in an industry have extensive knowledge of the processes and regulations, but could possibly overlook important issues due to complacency and routine behavior such as regular inspections of the same type of workplaces.

Through MSHA's lack of explosion related citations it would seem as though the Sago Mining Company was in compliance and not to blame for the explosion, even though they were cited for 149 non-contributory violations, such as seal strength. Though MSHA has many enforceable standards to prevent explosions and penalize companies in the event of an explosion, they do not seem to be as stringent on enforcement as OSHA, who uses any available resources to cite and penalize employers for noncompliance. For example, OSHA cited Imperial Sugar for 124 related violations with no specific combustible dust standard with which to cite them.

Since these devastating explosions, OSHA and MSHA seem to be on similar paths to prevent future explosions in their industry. In response to the Sago explosion MSHA made adjustments to their civil penalty assessments, revised the MINER Act, and established the Emergency Mine Evacuations standard and Seal Strengths, Design Applications, and Installations standard. Due to the Imperial Sugar explosion, OSHA has taken steps to increase their enforcement and industry awareness of combustible dust hazards through the revisions of their NEP, their announcements to amend combustible dust related standards and develop a general industry combustible dust hazard standard, and through increasing inspections in industries with increased combustible dust hazards.

In their increased inspections OSHA currently uses the General Duty Clause to cite combustible dust hazard violations. To do this OSHA references approximately 32 standards from several different standard-developing organizations. The most referenced standards come from NFPA and include: NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids;* NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agriculture and Food Processing Facilities;* and NFPA 69, *Standard on Explosion Prevention Systems* (National Archives and Records Administration, 2009).

Before MSHA instated their Emergency Mine Evacuation standard and Seal Strengths, Design Applications, and Installations standard, they established Emergency Temporary Standards until the Final Rule for each was put into regulation. This allows MSHA to enforce and ensure safe and healthy working conditions for miners when immediate dangers are present. According to the OSH Act of 1970, section 6, the Secretary of Labor also has the ability to establish an OSHA Emergency Temporary Standard should the secretary determine that exposure to a specific hazard would cause grave danger to employees and if it is determined that the temporary standard would protect worker from these hazards (OSHA, 1970). However, even with the devastating loss of life and property combustible dust explosions have caused, OSHA has yet to establish an emergency temporary standard to prevent further occurrence and require employers to provide a safe and healthy workplace free of combustible dust hazards.

Through my research I have concluded that though MSHA has several standards to help mitigate and prevent the risk of explosion, they do not seem to be strict enforcers of their regulations. I find it difficult to believe that an explosion could occur at a mine that was in compliance. The fact that there were no contributing citations indicates that either MSHA's standards are not extensive enough, or that they overlooked, ignored, or down-played explosion related violations. MSHA does however, seem to develop and implement much needed regulations in a timelier manner than OSHA, implementing two new standards within a year and a half of the Sago mine explosion.

OSHA, on the other hand, does not have a specific standard to mitigate or prevent the occurrence of combustible dust explosions. The process of implementing their Grain Handling standard took nearly 10 years. In order to prevent future combustible dust explosions they will need to mature the regulation making process so that vital regulations can be put into action quickly and effectively. They are, however, working intently on developing a standard and have responded to the Imperial Sugar explosion with great vigor. They have proven their stringent regulatory enforcement by citing Imperial Sugar with numerous violations. They are using the General Duty Clause and referencing other standards to cite violations and are continuously updating information and recommendations to prevent future incidents.

In summary, Table 1 depicts a comparison of the differences between MSHA's and OSHA's approach to preventing and responding to similar explosions.

Table 1: Comparison of MSHA and OSHA Prevention and Response

	MSHA: Sago Mine Explosion	OSHA: Imperial Sugar Explosion

Regulations	• 30 CFR 48 – Training and Retraining of Underground Miners
	• 30 CFR 49 – Mine Rescue Teams
	• 30 CFR 75 – Mandatory Safety Standards – Underground Coal Mines
		• No general industry standard for combustible dust hazards
		• 29 CFR 1910.272 – Grain Handling Facilities
		  ○ 272(d) – Emergency Action Plan
		  ○ 272(e) – Training
		  ○ 272(j) - Housekeeping
		  ○ 272(l) – Filter Collectors
		  ○ 272(m) – Preventive Maintenance
		  ○ 272(o) – Emergency Escape
		  ○ 272(p) – Continuous-flow Bulk Raw Grain Dryers
		  ○ 272(q) – Inside Bucket Elevators

Response Teams	Required by MSHA under 30 CFR 49 – Mine Rescue Teams	Only requirements for response/rescue teams are addressed in Confined Space Entry standard (29 CFR 1910.146)
Explosion Hazards	Methane and combustible coal dust	Combustible sugar dust
Explosion Prevention Methodologies	Ventilation, methane monitoring, housekeeping, and Rock dusting	Dust collection and filters, ventilation, belt alignment monitoring, bearing monitoring, routine inspections, preventive maintenance, dense phase conveying, equipment design
Incident Enforcement Citations	149 non-contributory violations cited	124 violations, 28 standards cited
Penalties	$0 – contributory	$4,050,000
Regulator Reaction	• Emergency Temporary Standard - Emergency Mine Evacuation Standard • PIB for MINER Act • Final Rule that changed current civil penalty assessment and codified MINER Act provisions • Emergency Temporary Standard – Sealing of Abandoned Areas • Seal Strengths, Design Applications, and Installments Standard	• Reissued Combustible Dust NEP • Announced intentions to revise housekeeping standard • Announced intentions to develop a General Industry Combustible Dust Standard • OSHA will be working with Imperial Sugar Co. to ensure health and safety become a priority

In order to protect lives, property, and communities from these devastating explosions, agencies need to focus on awareness. As previously mentioned, lack of awareness of combustible dust hazards was one of the contributing factors of the Imperial Sugar explosion. Similarly, lack of awareness of accumulated methane behind a mine seal was a contributing factor in the Sago Mine explosion. Awareness in the form of bulletins, standards, guidelines, publications, and training could allow industries to better understand the risks and hazards associated with their respective working environments.

An increased number of qualified MSHA and OSHA inspectors could help ensure industry compliance, therefore reducing explosion hazards. Continuous and frequent awareness and training should be a requirement for all agency inspectors. This will keep their inspection skills current and prevent routine behavior that could cause them to overlook significant violations and ensure they are following agency rules and guidelines before, during, and after inspections.

Similar to MSHA's response to the Sago Mine disaster, OSHA should consider implementing an Emergency Temporary Standard for combustible dust until a final rule is instated. This would require companies to mitigate combustible dust hazards and give OSHA a stronger regulatory stance when citing violations. When developing their own combustible dust hazard standard OSHA cannot repeat previously implemented standards. This will be difficult, considering the new standard will need to incorporate such issues as housekeeping, electrical equipment, mobile equipment, and walking/working surfaces. The best way to include these elements without repeating what is already regulated would be to adopt them by reference in the new standard and then build upon them in relation to specific combustible dust hazards. Using previously developed standards from organizations such as NFPA would give OSHA much of the information they would need to develop a combustible dust hazards standard of their own.

Industries need to use available information to reduce hazards in their facilities and ensure compliance with the appropriate agencies. Though a given issue is not an agency requirement does not mean it can or should be ignored. To ensure safe working environments, industries must go above and beyond what is required of them. Simply doing the minimum will not protect employees from harm. Health and safety must be a company priority. Employees and community support help to keep companies in operation. Without them there is no longer an operable or profitable business.

The following is a list of future research opportunities associated with this thesis:

1. Evaluate the public and media perceptions of industry explosions
2. Evaluate the public and media perceptions of MSHA and OSHA responses to explosions
3. Evaluate the impact these disasters have on the involved communities
4. Review MSHA and OSHA standard implementing processes and how they can be improved
5. Review MSHA and OSHA inspection policies and procedures to determine if there is opportunity for improvement
6. Determine the effectiveness of agency inspections

LIST OF REFERENCES

Bartec. (n.d). *Explosion Prevention.* Retrieved February 26, 2011 from http://www.bartec.de/homepage/eng/downloads/produkte/exschutz/Explosion protection.pdf.

Blair, A. (2007). Dust explosions and regulations in the United States. *Journal of Loss Prevention in Process Industries,* 20, 523-529.

Cashdollar, K. (2000). Overview of dust explosibility characteristics. *Journal of Loss Prevention Industries,* 13, 183-199.

Central Sugar Refinery. (2008). *Sugar FAQ's – about sugar.* Retrieved November 16, 2010 from http://www.central-sugars.com.my/faq.htm.

Clark, J. (n.d). *How can sugar explode?* Retrieved November 16, 2010 from http://science.howstuffworks.com/sugar-explode.htm/printable.

CNN. (2010). *Obama to eulogize 29 lost miners.* Retrieved April 21, 2010 from http://politicalticker.blogs.cnn.com/2010/04/19/obama-to-eulogize-29-lost-miners/?fbid=URxt2kqPYS7.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications.

CSB. (2009). *Investigation report: sugar dust explosion fire(14 killed, 36 injured).* Retrieved November 16, 2010 from http://www.csb.gov/assets/document/Imperial_Sugar_Report_Final_updated.pdf.

Earls, A. (2010). *Refining the process.* Retrieved January 26, 2011 from http://www.nfpa.org/publicJournalDetail.asp?categoryID=1965&ID=46404&src=NFPAJournal&cookie%5Ftest=1.

Eckhoff, R. (1996). Prevention and mitigation of dust explosions in the process industries: a survey of recent research & development. *Journal of Loss Prevention Industries,* 9(1), 3-20.

Environmental Protection Agency. (1998). *Bituminous and subbituminous coal combustion*. Retrieved April 22, 2010, from http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s01.pdf.

Geddie, J. (n.d). *A guide to combustible dust.* Retrieved January 25, 2011 from http://www.nclabor.com/osha/etta/indguide/ig43.pdf.

Jeffries, K. (2010). *A comprehensive approach to combustible dust management.* Retrieved February 11, 2011 from http://www.nfpa.org/assets/files/PDF/Proceeding/Jeffries_presentation.pdf.

Joseph, G. (2007). Combustible dusts: a serious industrial hazard. *Journal of Hazardous Materials,* 142(3), 589-591. doi:10.1016/j.jhazmat.2006.06.12 7

KET. (2005). *How coal is produced*. Retrieved April 21, 2010 from http://www.ket.org/Trips/Coal/AGSMM/agsmmproduced.html.

MSHA. (1998). *Winter alert reminds coal miners: "don't let up on safety" in cold weather months.* Retrieved April 16, 2010 from http://www.msha.gov/MEDIA/PRESS/1998/NR980916.HTM.

MSHA. (2007a). *U.S. mine safety and health administration pursues new regulations on sealed areas based on finding of its sago mine accident investigation.*

Retrieved April 16, 2010 from http://www.msha.gov/MEDIA/PRESS/2007/NR070509.asp.

MSHA. (2007b). *Report of Investigation: fatal underground coal mine explosion, sago mine, wolf run mining company.* Washington, DC: U.S. Government Printing Office.

MSHA. (2007c). *Internal review of MSHA's actions at the sago mine wolf run mining company sago, Upshur county, West Virginia.* Washington, DC: US. Government Printing Office.

MSHA. (n.d.a). *MSHA's occupational illness and injury prevention program health topic: carbon monoxide.* Retrieved April 16, 2010 from http://www.msha.gov/Illness_Prevention/healthtopics/carbonmonoxide.htm.

MSHA. (n.d.b). *Rock dusting.* Retrieved April 16, 2010 from http://www.msha.gov/S&HINFO/RockDusting/RockDusting.asp.

MSHA. (n.d.c). *MSHA's mission*. Retrieved April 16, 2010 from http://www.msha.gov/MSHAINFO/MISSION.HTM.

MSHA. (n.d.d). *Title 20 CFR Parts 1 through 199*. Retrieved April 23, 2010 form http://www.msha.gov/30CFR/CFRINTRO.HTM.

NFPA. (2006). *Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids.* National Fire Protection Association: Quincy, MA.

NFPA. (2008). *Fire protection handbook* (20th ed.). Quincy: NFPA.

National Archives and Records Administration. (2009). *Federal register: Combustible dust; proposed rule*. FR Doc. E9–25075.

NIOSH. (2006). *Float coal dust explosion hazards.* Retrieved April 20, 2010 from http://www.cdc.gov/niosh/mining/pubs/pdfs/2006-125.pdf.

OSHA. (1970). *Occupational safety and health standards.* Retrieved March 19, 2011 from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=OSHACT&p_id=3360.

OSHA. (2002). *Grain handling facilities*. Retrieved February 27, 2011 from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9874.

OSHA. (2008). *Combustible dust national emphasis program (reissued).* Retrieved January 25, 2011 from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id3830.

OSHA. (2009). *Status report on combustible dust national emphasis program.* Retrieved November 16, 2010 from http://www.osha.gov/dep/combustible_dust/combustible_dust_nep_rpt_102009.html.

OSHA. (2010a). *Combustible dust pentagon*. OSHA handbook. Retrived February 27, 2011 from http://www.pachamber.org/www/products/publications/pdf/10-12OSHA%20Handbook%20Pages.pdf.

OSHA. (2010b). *US department of labor announces Imperial Sugar will pay more than $6 million and implement extensive safety and health abatement measures.* Retrieved January 18, 2011 from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=17955.

OSHA. (n.d.a). *About OSHA.* Retrieved March 4, 2011 from http://www.osha.gov/about.html.

OSHA. (n.d.b). *Hazard alert: combustible dust explosions.* Retrieved November 16, 2010 from http://www.osha.gov/OshDoc/data_General_Facts/OSHAcombustibledust.pdf.

OSHA. (n.d.c). *Regulations (standard – 29 CFR).* Retrieved March 4, 2011 from http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1910.

OSHA. (n.d.d). *Inspection: 310988712 – Imperial Sugar Company: Imperial Savannah, L.P.* Retrieved January 25, 2011 from http://www.osha.gov/pls/imis/establishment.inspection_detail?id=310988712.

Sapko, M., Cashdollar, K., & Green, G. (2007). Coal dust particle size survey of US mines. *Journal of Loss Prevention in the Process Industries, 20,* 616-620.

Sapko, M., Weiss, E., Cashdollar, K., & Zlochower, A. (n.d.). *Experimental mine and laboratory dust explosion research at NIOSH.* Retrieved April 16, 2010 from http://www.cdc.gov/niosh/mining/pubs/pdfs/emald.pdf.

Skidel Sugar Refinery. (n.d). *Production: Process diagram*. Retrieved March 6, 2011 from http://www.ssf.by/eng/proc/proc_3.html.

SKIL. (n.d.a). *How sugar is made – an introduction.* Retrieved on November 16, 2010 from http://www.sucrose.com/learn.html.

SKIL. (n.d.b). *How cane sugar is made – the basic story.* Retrieved November 16, 2010 from http://www.sucrose.com/lcane.html.

SKIL. (n.d.c). *How beet sugar is made – the basic story.* Retrieved November 16, 2010 from http://www.sucrose.com/lbeet.html.

Skow, M., Kim, A., & Deul, M. (1980). *Creating a safer environment in U.S. coal mines.* Washington, DC: U.S. Government Printing Office.

Stephan, C. (n.d.). *Coal dust explosion hazards.* Retrieved April 16, 2010 from http://www.msha.gov/S&HINFO/TECHRPT/P&T/COALDUST.pdf.

Sugar Association. (n.d). *Refining.* Retrieved November 16, 2010 from http://www.sugar.org/sugar-basics/refining.html.

Ulery, J. (2008). *Explosion hazards from methane emissions related to geologic features in coal mines.* Retrieved April 21, 2010 from http://www.cdc.gov/niosh/mining/pubs/pdfs/2008-123.pdf.

UMWA. (n.d.a). *Who we are, where we work: longwall mining.* Retrieved April 21, 2010 from http://www.umwa.org/index.php?q=content/longwall-mining.

UMWA. (n.d.b). *Who we are, where we work: room and pillar mining.* Retrieved April 21, 2010 from http://www.umwa.org/index.php?q=content/room-and-pillar-mining.

Weirick, M. L., & Manjunath, K. (2009). Short communication: layers of protection analysis (LOPA). *Particle Science & Technology,* 27(1), 89-96. doi:10.1080/02726350802612042

APPENDIX A:

Map of Wolf Run Mining Company's Sago Mine Explosion

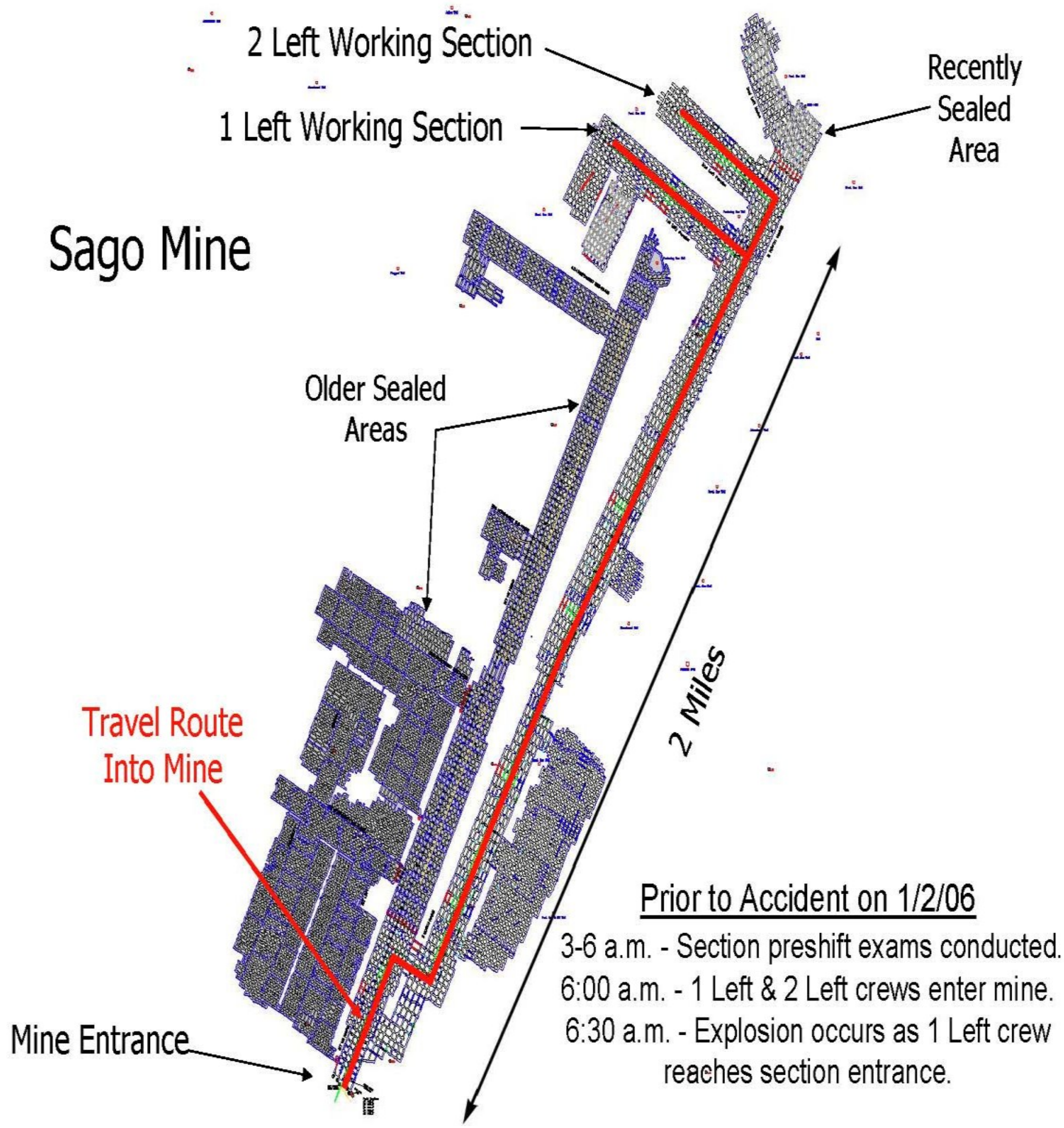

Figure 4: Map of Sago Mine

Source: Map depicts the layout of the Sago Mine at the time of the 2006 explosion. Taken from "Sago Mine," by MSHA, Retrieved November 16, 2010 from http://www.msha.gov/sagomine/PowerPoint/SagoMap.pdf.

APPENDIX B:

Maps of Imperial Sugar Company's Refinery Explosion

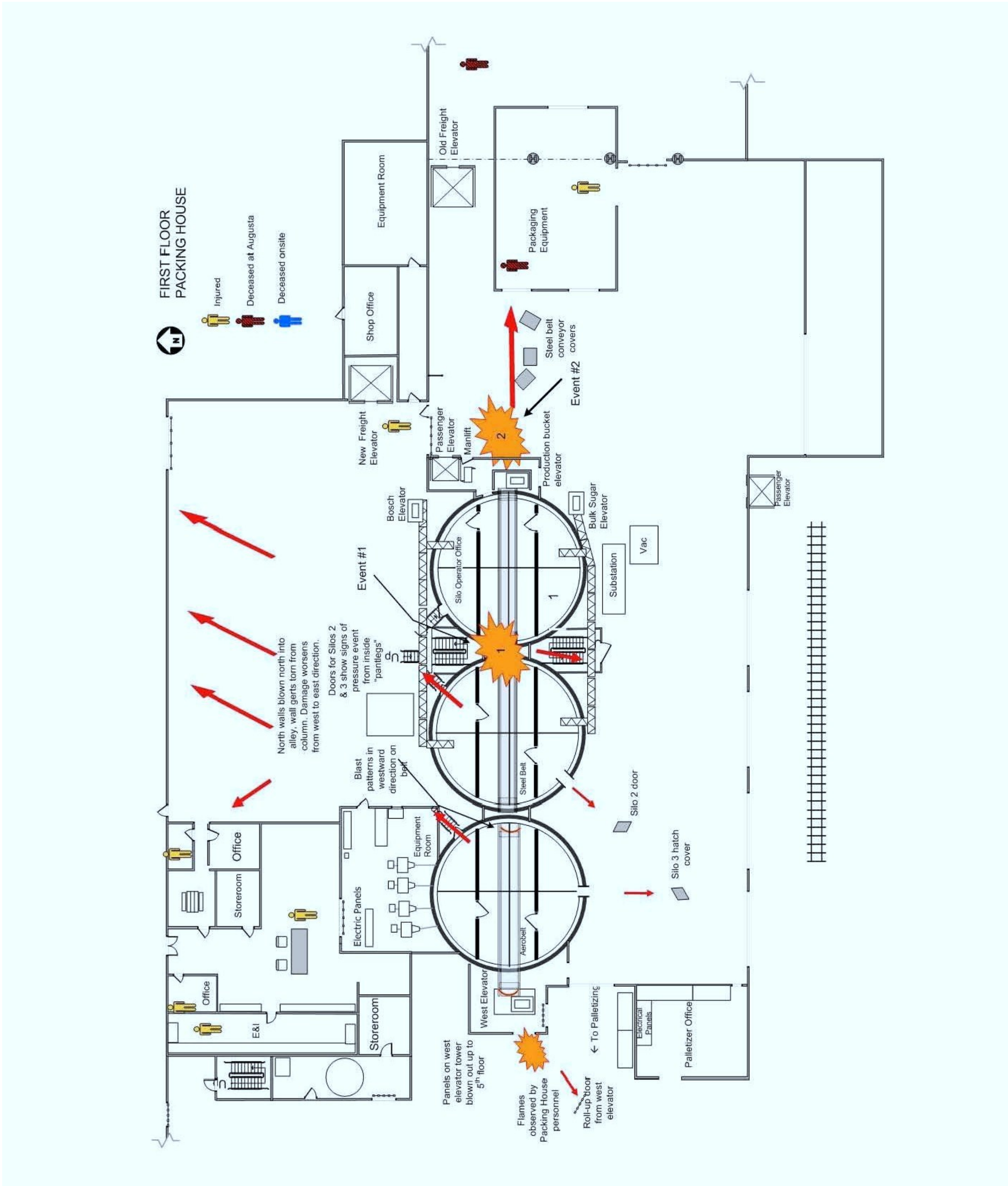

Figure 5: Map of First Floor Packaging House

Source: Map depicts explosion impact of the first floor packaging house at the Imperial Sugar refinery. Taken from "Investigation Report: Sugar Dust Explosion Fire (14 killed, 36 injured)," by CSB, Retrieved November 16, 2010 from http://www.csb.gov/assets/document/Imerial_Sugar_Report_Final_updated.pdf.

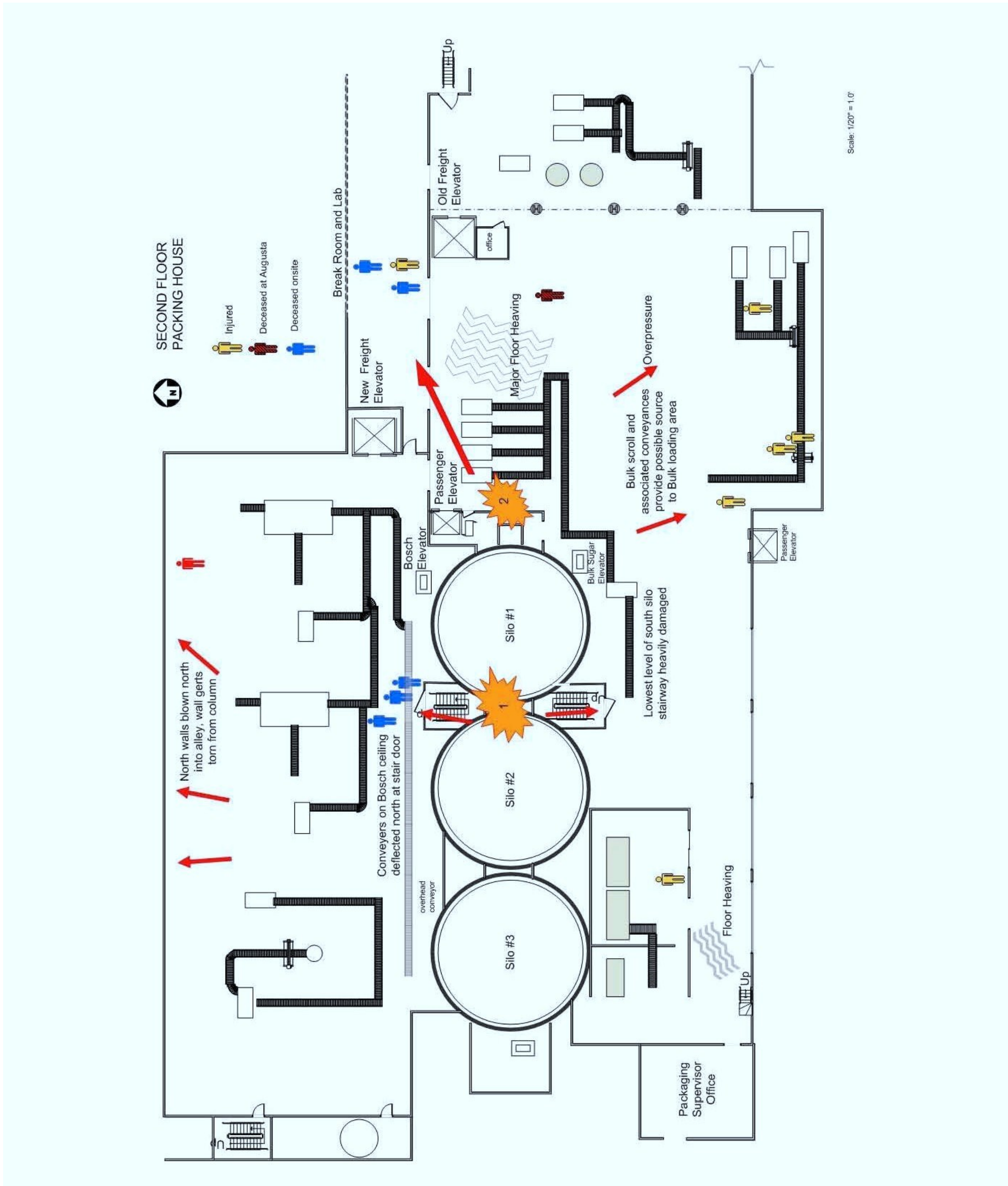

Figure 6: Map of Second Floor Packaging House

Source: Map depicts explosion impact of the second floor packaging house at the Imperial Sugar refinery. Taken from "Investigation Report: Sugar Dust Explosion Fire (14 killed, 36 injured)," by CSB, Retrieved November 16, 2010 from http://www.csb.gov/assets/document/Imerial_Sugar_Report_Final_updated.pdf.

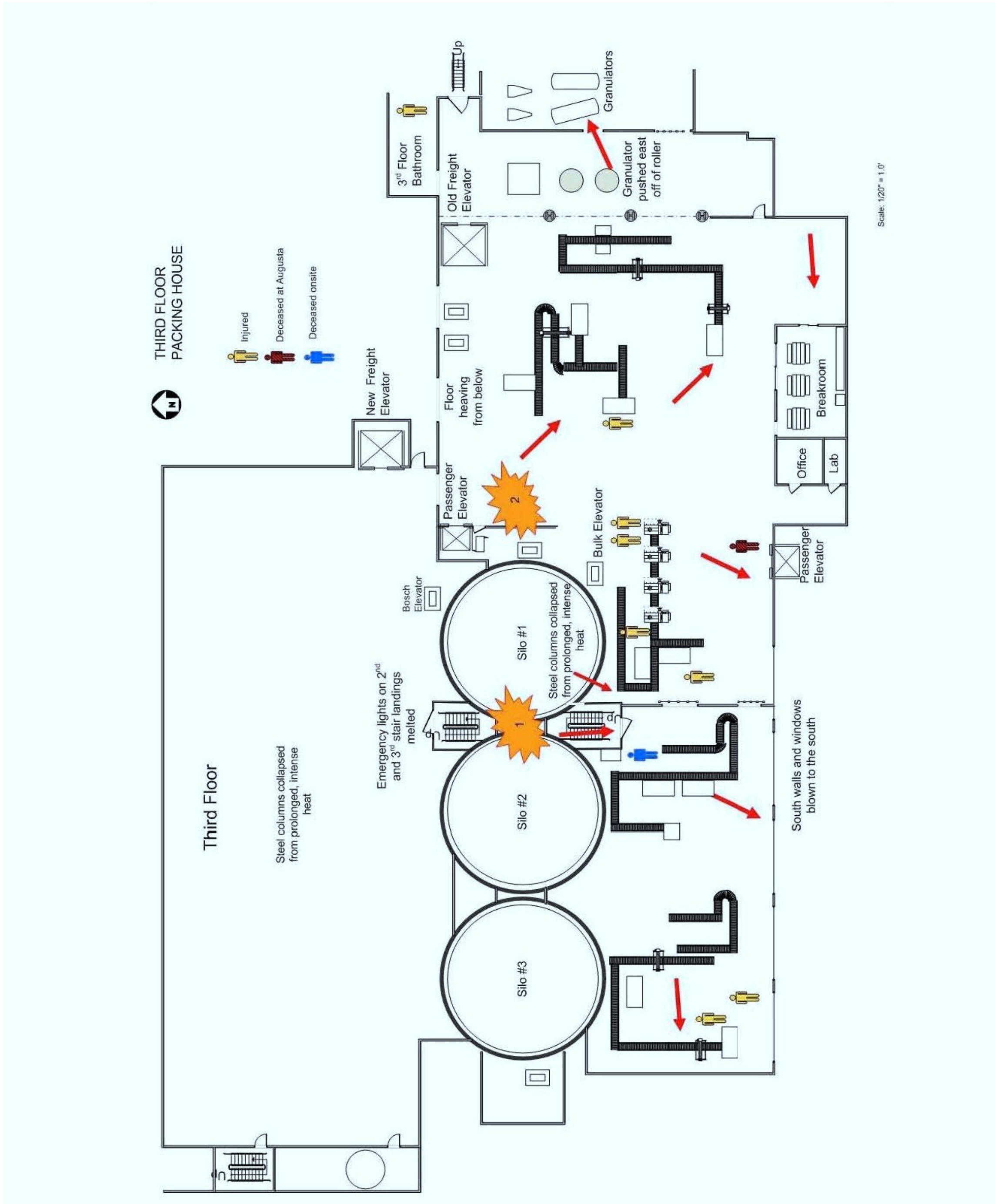

Figure 7: Map of Third Floor Packaging House

Source: Map depicts explosion impact of the third floor packaging house at the Imperial Sugar refinery. Taken from "Investigation Report: Sugar Dust Explosion Fire (14 killed, 36 injured)," by CSB, Retrieved November 16, 2010 from http://www.csb.gov/assets/document/Imerial_Sugar_Report_Final_updated.pdf.

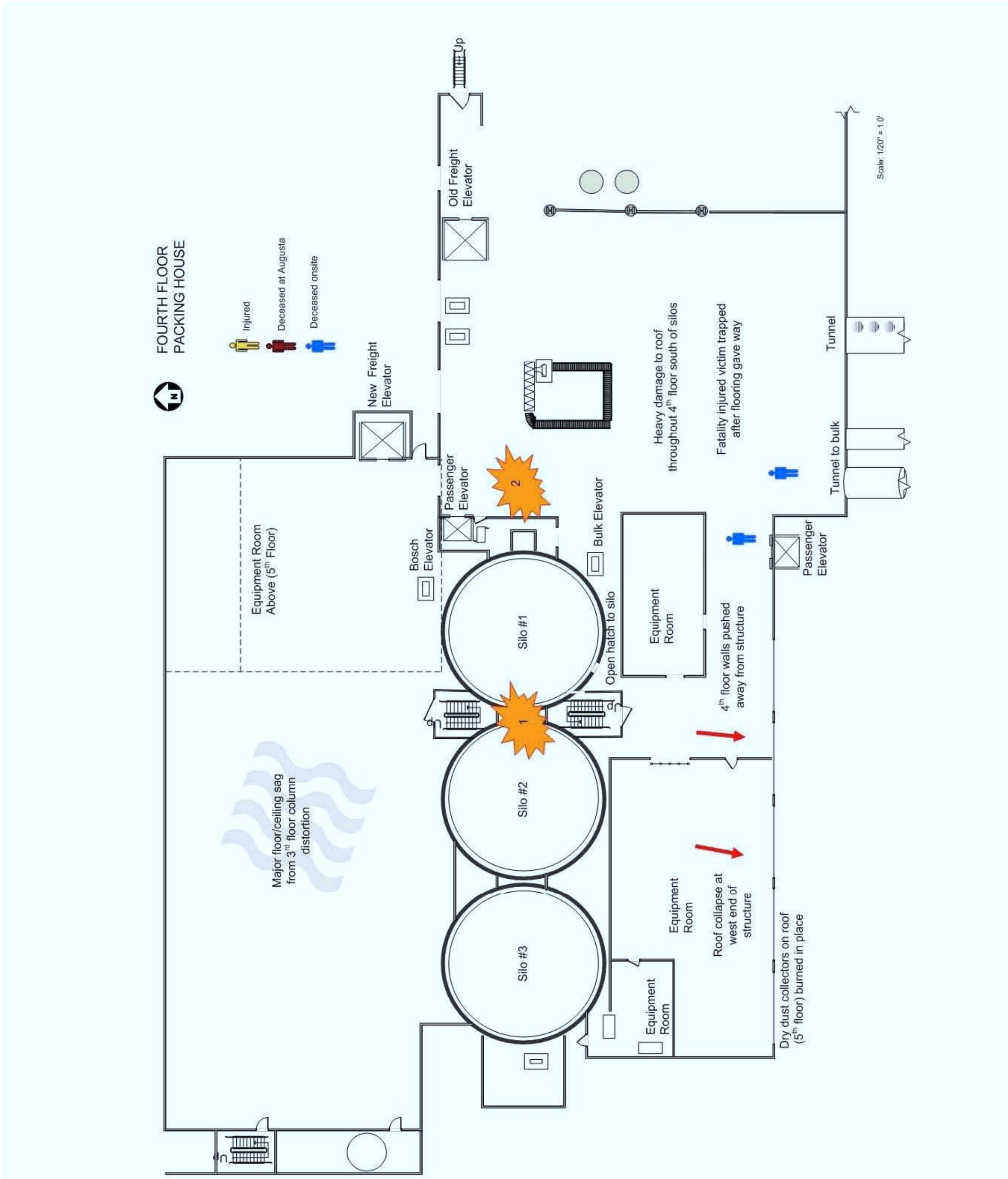

Figure 8: Map of Fourth Floor Packaging House

Source: Map depicts explosion impact of the fourth floor packaging house at the Imperial Sugar refinery. Taken from "Investigation Report: Sugar Dust Explosion Fire (14 killed, 36 injured)," by CSB, Retrieved November 16, 2010 from http://www.csb.gov/assets/document/Imerial_Sugar_Report_Final_updated.pdf.