U.S. Chemical Safety and Hazard Investigation Board

Fatal Combustible Dust Explosions at Didion Milling Inc.

Cambria, Wisconsin | *Incident Date: May 31, 2017* | **No. 2017-07-I-WI**

Investigation Report

Published: December 2023

SAFETY ISSUES:

- Process Hazard Recognition
- Dust Hazard Analysis
- Engineering Controls for Combustible Dust Hazards
- Structural Design for Combustible Dust Hazards
- Fugitive Dust Management
- Management of Change
- Incident Investigations
- Process Safety Information
- Management of Audits and Inspections
- Emergency Preparedness
- Personal Protective Equipment
- Process Safety Leadership
- Regulatory Coverage of Combustible Dust

U.S. Chemical Safety and Hazard Investigation Board

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The May 31, 2017, combustible dust explosions at the Didion Milling Facility fatally injured five people:

Duelle Block

Robert Goodenow

Carlos “Charly” Nuñez Contreras

Angel Reyes

Pawel Tordoff

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ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society of Testing and Materials
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
DHA	Dust Hazard Analysis
ERP	Emergency Response Plan
FDA	Food and Drug Administration
GMP	Good Manufacturing Practices
HACCP	Hazard Analysis and Critical Control Points
HAL	Hazard Alert Letter
IBC	International Building Code
IFC	International Fire Code
ISO	International Organization for Standardization
LEL	Lower Explosive Limit
MEC	Minimum Explosible Concentration
MIE	Minimum Ignition Energy
MIT	Minimum Ignition Temperature
MOC	Management of Change
MSI	Monthly Sanitation Inspections
MSP	Master Sanitation Program
MSS	Master Sanitation Schedule
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PCM	Pregelatinized Corn Meal
PHA	Process Hazard Analysis
PPE	Personal Protective Equipment
PSI	Process Safety Information
PSM	Process Safety Management
SDS	Safety Data Sheet
USDA	United States Department of Agriculture

FIGURES

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Executive Summary

On Wednesday, May 31, 2017, at approximately 11:00 p.m., multiple combustible dust explosions occurred at the Didion Milling, Inc. (Didion) dry corn milling facility in Cambria, Wisconsin, fatally injuring five employees and injuring another 14 employees. Didion employed 124 people at the Cambria site, of which 19 employees were onsite at the time of the incident.

During the day of the incident, Didion connected the discharge of two rotary gap mills in an attempt to increase production. On the night of the incident, during normal mill facility operations, employees smelled smoke in parts of the mill. Employees investigated the source of the smoke in the milling process areas and determined that the source of the smoke likely was located on the first floor of one of the buildings. While investigating process equipment for the source of the smoke, several employees heard an explosion and subsequently saw fire emanate from piping on the rotary gap mill equipment discharge. The employees began to evacuate and attempted to notify other employees of the emergency using their radios; however, conflicting radio traffic caused confusion with the intended message.

A fire, a type of deflagration,[a] spread through the process equipment via interconnected dust collection systems resulting in explosions in some of the dust collection equipment. As the deflagrations relieved from the process equipment, secondary explosions occurred throughout the facility. The employees who were not within the immediate vicinity of the observed fire were unaware of the emergency and the need to evacuate prior to the explosions.

The explosions resulted in the collapse of multiple buildings of the mill facility. The Multipurpose Building, F Mill, and the Boiler House suffered complete collapses. D Mill suffered significant structural damage, rendering it inaccessible after the incident. Portions of B Mill were significantly damaged, which prevented access to portions of the building. Didion's estimated property damage from the incident is $15,375,959. No off-site damage or consequences were reported following the incident.

[a] A deflagration is a propagating reaction which propagates spatially through the reaction mass, such as a combustible dust, that moves slower than the speed of sound [7, pp. 10-11]. Examples of deflagrations are fires, flash fires, and explosions.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Process Hazard Recognition.** Didion did not accurately assess a number of process streams in the mill buildings that contained combustible dust hazards. As a result, Didion's process designs lacked several safeguards and did not follow design good practices, which if followed, could have prevented the incident or reduced its severity. Among these were:
  - The failure to recognize that interconnecting equipment through dust collectors could present a deflagration propagation hazard;
  - The incorrect conclusion, using incorrect calculations, that the dust collectors in the mill facility did not contain explosive dust concentrations;
  - The failure to recognize that proper design and verification of ductwork system sizing and performance are crucial for safe dust collector operation and pneumatic conveying; and
  - The failure to correctly design and maintain these systems allowed combustible material to accumulate inside ductwork systems, contributing to the incident's severity. (Section 4.1)

- **Dust Hazard Analysis.** Dust hazard analyses (DHAs) are assessments of processes to determine potential combustible dust hazards and are outlined by guidance from the National Fire Protection Association (NFPA). DHAs are used to identify engineering controls needed to maintain safe operations during normal and upset conditions. While the NFPA guidance was published in 2015, Didion had not performed any analyses of the grain handling processes for potential fire and explosion hazards. To date, the *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not require a DHA for compliance. (Section 4.2)

- **Engineering Controls for Combustible Dust Hazards.** Engineering controls for the prevention and mitigation of combustible dust fires, flash fires, and explosions are widely used throughout industry, and their application is outlined by the NFPA. Controls of combustible dust hazards are categorized into, but are not limited to: pre-deflagration detection, deflagration venting, deflagration isolation, deflagration suppression, and deflagration containment. Each of these control strategies alone is not sufficient to mitigate or prevent an ignition; however, when used in conjunction with one another, deflagration hazards can be effectively controlled to prevent or mitigate the damage caused by combustible dust explosions.

  The lack of engineering controls for the control and mitigation of combustible dust fires and explosions throughout the Didion milling facility allowed the propagation of the fire, resulting in deaths, injuries, and damage to the facility. Ensuring the proper use of deflagration controls when processing combustible dust can prevent or mitigate explosions. The NFPA provides guidance for selecting and implementing deflagration protection systems. (Section 4.3)

- **Structural Design for Combustible Dust Hazards.** The mill buildings were not designed to relieve the pressure generated from a combustible dust explosion that could occur within the milling facility during an upset condition. The mill buildings lacked deflagration vents that could relieve pressure and mitigate the damage that occurred due to the propagation of the pressure wave through the mill from secondary dust explosions. Furthermore, the mill buildings were not designed to withstand deflagration pressures which exacerbated the facility damage and injuries due to the collapse of the buildings.

Ensuring the proper design of facilities to withstand explosions or relieve deflagration pressures using deflagration controls when processing combustible dust can prevent or mitigate structural damage or collapse. The NFPA provides guidance for selecting and implementing structural deflagration protection systems. Additional guidance for building design is provided for building codes. (Section 4.4)

- **Fugitive Dust Management.** As a facility that produced food for human consumption, Didion followed food safety standards designed to ensure that its products were safe for the consumer. Didion also used many of these food safety management systems to manage combustible dust hazards, but the food safety standards Didion followed were not intended to protect against combustible dust hazards. Didion's use of food safety standards to address combustible dust hazards created gaps in process safety at the mill facility, particularly for combustible dust propagation hazards and around dust collectors. (Section 4.5)

- **Management of Change.** While Didion had a Management of Change program as part of the food safety program, the program did not assess changes for combustible dust hazards. Didion's weak management of change program allowed changes to occur in the processes without the evaluation of potential hazards. (Section 4.6)

- **Incident Investigations.** Prior to the incident on May 31, 2017, Didion had experienced several fires and smoldering material incidents that could have resulted in more significant fires and explosions. Didion's failure to thoroughly investigate prior incidents involving fires and smoldering events prevented Didion from implementing corrective actions that could prevent or mitigate fires and explosions within the mill facility. The failure to address the causes of the prior incidents indicated a weak incident investigation program that did not adequately address hazards that could be mitigated or prevent future incidents. (Section 4.7)

- **Process Safety Information.** Process safety information is critical for companies to be able to identify and mitigate hazards at facilities. Prior to the incident, Didion did not maintain key process safety information, such as deflagration engineering control design documentation, dust collector design information, or dust explosibility data. The lack of this critical information allowed Didion to make changes to the process without consideration of the potential hazards and contributed to the interconnected and unprotected design that allowed explosions and propagations to go unmitigated during the incident. (Section 4.8)

- **Management of Audits and Inspections.** In the years leading up to the incident, Didion underwent several audits and inspections by external parties, including the Occupational Safety Health Administration (OSHA) and Didion's insurance carrier. These inspections identified the potential for combustible dust hazards, including propagation of fire resulting in multiple explosions and collapse of the buildings. The failure to address the hazards identified by external parties as well as the turnover of responsible management staff left the facility at risk of fires and explosions. Employers should utilize the findings of external audits to identify and correct hazards that could result in significant incidents. (Section 4.9)

- **Emergency Preparedness.** Didion's emergency response plan failed to adequately prescribe actions to be taken by employees and management during fire incidents. During emergency response events, employees of the mill relied on radios to trigger evacuations; however, during the incident, conflicting radio traffic prevented employees from being able to evacuate prior to the explosions and collapse of the building. Didion lacked a facility-wide notification system that could immediately notify all employees of the need to evacuate or of an ongoing emergency.

  Adequately assessing potential emergency situations and required responses is necessary for employers to protect employees from hazards. The lack of a well-defined emergency response plan in conjunction with an upset condition places employees in hazardous situations. (Section 4.10)

- **Personal Protective Equipment.** Didion did not require the use of fire-resistant clothing within the milling facility, although Didion previously experienced a combustible dust flash fire that resulted in an employee suffering burn injuries. The personal protective equipment prescribed by Didion did not protect the employees from the flames they were exposed to during the explosions and propagation that occurred on the night of the incident. The NFPA provides guidance for the use of fire-resistant clothing for short-term exposures during upset conditions. (Section 4.11)

- **Process Safety Leadership.** Process safety leadership is one factor that affects the safety culture of a facility. Didion's poor safety culture and inadequate leadership on safety issues allowed the normalization of deviance regarding smoldering fires, a lack of deference to expertise, a lack of a sense of vulnerability, and inadequate understanding of the combustible dust and deflagration hazards present at Didion. The combination of these factors and decisions made by Didion leadership contributed to the inadequate engineering controls, over-reliance on administrative controls, and inadequate emergency response planning at the time of the incident. (Section 4.12)

- **Regulatory Coverage of Combustible Dust.** Combustible dusts are capable of undergoing flash fires and explosions with severe impacts to people, property, and the environment. Combustible dusts present a hazard in several industries, including food, agriculture, and polymers. Yet, combustible dusts are not regulated under a comprehensive OSHA Combustible Dust rule. Didion was required to follow OSHA's *Grain Handling Facilities Standard*; however, this standard does not incorporate safety management systems, such as incident investigations, management of change, and dust hazard analysis. Had combustible dust hazards been addressed by a safety management system in a regulatory standard, such as OSHA's Process Safety Management (PSM) standard or a comprehensive Combustible Dust rule, Didion could have been required to implement risk mitigation and management systems that could have prevented the circumstances that occurred on the night of the incident. (Section 4.13)

Cause

The CSB determined the cause of the dust explosions and collapsed buildings was the ignition of combustible corn dust inside process equipment, which transitioned to multiple explosions. Contributing to the severity of the explosions was Didion's lack of engineering controls, which allowed the fire and explosions to propagate through the facility uncontrolled. The uncontrolled propagation of fire and explosions subsequently caused secondary explosions due to the inadequate fugitive dust management.

Due to the number of weaknesses in the implementation and management of safety programs, Didion exhibited a lack of safety leadership and a poor safety culture. Didion's inadequate safety management systems for combustible dust failed to mitigate the potential hazards of combustible dust in the process. Didion inadequately managed changes to process equipment, failed to maintain critical safety information, and failed to incorporate lessons learned from prior incidents.

Didion's inadequate emergency preparedness, which failed to inform or train its employees to safely respond to a smoldering fire, contributed to the fatalities and serious injuries. Also contributing to at least one fatality and three serious injuries was Didion's lack of flame-resistant personal protective equipment that could have protected employees from exposure to the flash fires.

Contributing to all five fatalities and all 14 serious injuries was Didion management's failure to abate combustible dust hazards identified during external inspections, which resulted in Didion continuing to operate despite knowledge of these hazards.

Recommendations

Previously Issued Recommendations Superseded in This Report

To Occupational Safety and Health Administration (OSHA)

2006-1-H-1 (From the 2006 Combustible Dust Hazard Investigation), 2008-05-I-GA-R11 (From the 2008 Imperial Sugar Investigation), and 2011-04-I-TN-R2 (From the 2011 Hoeganaes Corporation Flash Fires Investigation

Issue a standard designed to prevent combustible dust fires and explosions in general industry. Base the standard on current National Fire Protection Association (NFPA) dust explosion standards (including NFPA 654 and NFPA 484), and include at least - hazard assessment, - engineering controls, - housekeeping, - building design, - explosion protection, - operating procedures, and - worker training.

Superseded by **2017-07-I-WI-R10** *to OSHA in Section 6.2.2*

2011-4-I-TN-1 (From the 2011 Hoeganaes Corporation Flash Fires Investigation)

Ensure that the forthcoming OSHA Combustible Dust Standard includes coverage for combustible metal dusts including iron and steel powders.

Superseded by **2017-07-I-WI-R10** *to OSHA in Section 6.2.2*

New Recommendations

To Didion Milling, Inc. (Didion)

2017-07-I-WI-R1

Contract a competent third party to develop a comprehensive combustible dust process safety management system, such as OSHA's *Process Safety Management* standard or the requirements in the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust,* Chapter 8, which includes, at a minimum, the following elements:

a. Management of Change for combustible dust;
b. Process Safety Information management;
c. Management of Audits and Inspections;
d. Fugitive Dust Management;
e. Incident Investigation;
f. Dust Hazard Analyses;
g. Management of Engineering Controls for combustible dust;
h. Personal Protective Equipment; and
i. Emergency Preparedness.

2017-07-I-WI-R2

Contract a competent third party to develop and implement modifications to the pneumatic conveying and dust collector ductwork systems in accordance with guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, to include, at a minimum:

a. Ensure minimum required transport velocity is maintained throughout the system.
b. Implement a periodic inspection and testing program for pneumatic conveying and dust collector ductwork systems, following industry guidance such as NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids,* and FM Global guidance. The program should include cleaning on a set frequency and measuring transport velocities on a routine basis to ensure proper system function.

2017-07-I-WI-R3

Contract a competent third party to perform dust hazard analyses (DHAs) on all buildings and units that process combustible dust. Ensure that the DHAs are revalidated at least every five years. Implement pre-deflagration detection, deflagration venting, deflagration suppression, deflagration isolation, and deflagration pressure containment engineering controls identified in the initial and revalidation DHA in accordance with NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, NFPA 69, *Standard on Explosion Prevention Systems*, and NFPA 652, *Standard on the Fundamentals of Combustible Dust*.

2017-07-I-WI-R4

Contract a competent third party to assess and implement engineering controls for the structural design and venting requirements of the reconstructed facility to ensure they meet the requirements and guidance in NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, for adequacy of venting capacity.

2017-07-I-WI-R5

Incorporate recording any paper-based process safety information into Didion's existing electronic records management system so that the information can be reliably retained, retrieved, and analyzed in the event of a catastrophic incident.

2017-07-I-WI-R6

Contract a competent third party to perform personal protective equipment hazard analyses, such as those prescribed by NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* and require appropriate flame-resistant garments for all operations that handle combustible dusts during normal and upset conditions.

2017-07-I-WI-R7

Contract a competent third party to update the facility emergency response plan and train all employees on updated emergency response plan. The update should include the guidance in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, and NFPA 652, *Standard on the Fundamentals of Combustible Dust,* Chapter 8 and Section A.8.10.1, which includes, at a minimum, the following elements:

a. A signal or alarm system;
b. Emergency shutdown procedures;
c. Provide instructions for when and how to trigger emergency evacuations;
d. Provide instructions for when to notify emergency responders for need of assistance;
e. Response to potential fire scenarios, such as smoldering fires inside equipment; and
f. Prevent firefighting of process fires inside equipment.

2017-07-I-WI-R8

Contract a competent third party to assess and update the pre-deflagration detection and suppression engineering controls, such as those discussed in Chapter 9 of the 2019 edition of NFPA 69, *Standard on Explosion Prevention Systems*, for adequacy to detect and alarm employees of an emergency situation, such as a smoldering fire, and trigger an evacuation.

2017-07-I-WI-R9

Contract a competent third party to develop and implement a process safety leadership and culture program, based on the guidance of the CCPS's *Guidelines for Auditing Process Safety Management Systems* and *Process Safety: Leadership from the Boardroom to the Frontline*. The program should include, at a minimum, the following elements:

a. A process safety policy;
b. A process safety leadership and culture committee;
c. Appropriate goals for process safety;
d. A commitment to process safety culture;
e. Leading and lagging process safety metrics;
f. Process Safety Culture Assessments; and
g. Engagement with external process safety leadership and culture experts.

To the Occupational Safety and Health Administration:

2017-07-I-WI-R10

Promulgate a standard for all industries that handle combustible dust, which should be based on the requirements of current NFPA combustible dust standards, including NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 484, *Standard for Combustible Metals*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, NFPA 655, *Standard for Prevention of Sulfur Fires and Explosions*, NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities,* or a successor standard. At a minimum, the standard should include the following elements:

a. Hazard Recognition;
b. Dust Hazard Analysis;
c. Management of Change;
d. Incident Investigation;
e. Engineering Controls;
f. Building Design;
g. Fugitive Dust Management;
h. Operating Procedures;
i. Process Safety Information;
j. External Audit Management;
k. Training;
l. Emergency Response; and
m. Personal Protective Equipment.

2017-07-I-WI-R11

Following implementation of CSB Recommendation No. 2017-07-I-WI-R10, update the *Grain Handling Facilities Standard* to clarify grain handling facilities with combustible dust are covered by the new Combustible Dust Standard.

2017-07-I-WI-R12

Develop a program to trigger follow-up inspections when hazard alert letters are issued for combustible dust hazards and there is insufficient evidence to demonstrate that those hazards have been abated.

To the National Fire Protection Association (NFPA):

2017-07-I-WI-R13

Update NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, or a successor standard, to incorporate, at a minimum, the following elements:

1. Unify the requirements for performing dust hazard analyses to remove equipment exemptions and require the assessment of all processes, such as cyclones, as required in:
    a. The 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*.
    b. Chapters 3, 5, and 6 of the CCPS's *Guidelines for Combustible Dust Hazard Analysis*.
2. Incorporate the additional guidance for Management of Change to include but not limited to:
    a. Harmonize the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, requirements for section 8.12.2.4, modifications to operating and maintenance procedures, and section 8.12.2.4, employee training requirements.
    b. Chapter 3 and Appendix B of the CCPS's *Guidelines for the Management of Change for Process Safety,* such as addressing temporary changes, operating and maintenance procedures, employee training, and dust testing results, to standardize MOC requirements across all industries that handle combustible dust.
3. Update the requirements for incident investigation management systems, to include but not limited to:
    a. Incorporate the optional guidance of the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, as a mandatory requirement.
    b. Chapters 4 and 10 of CCPS's *Guidelines for Investigating Process Safety Incidents (3rd Edition)*.

1 BACKGROUND

1.1 DIDION MILLING

Didion Milling Inc. (Didion) is a family-owned agricultural processing company. Didion operates: a dry corn mill facility in Cambria, Wisconsin; a soybean mill facility in Johnson Creek, Wisconsin; and a packaging facility in Markesan, Wisconsin. Didion[a] operates an ethanol plant across the road from the corn mill facility in Cambria that was connected to the mill facility[b] by a conveyor by which corn was sent to the ethanol plant for processing [1, p. 3].

The incident occurred at Didion's dry corn mill facility in Cambria. The mill facility was initially constructed in 1991, and expansions of the facility occurred until the final building was constructed in 2012. Although the ethanol plant was interconnected with the mill facility, the plant was not involved in the incident and did not sustain any damage from the event. **Figure 1** below shows the mill facility before the incident.

Figure 1: Didion mill facility prior to the explosion. (Credit: Didion)

1.1.1 DESCRIPTION OF THE SURROUNDING AREA

As shown in **Figure 2**, the mill facility is on the outskirts of the Village of Cambria. Located adjacent to the mill facility is a Seneca Foods Corporation facility, which is highlighted in green. Approximately 1000 feet to the south of the Didion facility, there is residential housing. The Cambria-Friesland Middle School and High School

[a] Didion Bioscience was known as Didion Ethanol at the time of the incident and is referred to as such in this report, as source material refers to Didion Ethanol only.

[b] Throughout this report, "Didion" and "mill facility" refer to the Cambria, Wisconsin milling site where the incident occurred, unless noted otherwise. "Didion Milling" refers to the corporate entity as a whole.

are approximately one-quarter mile to the north of the Didion facility, highlighted in blue. The town of Cambria is located within the one-mile radius of the Didion facility. **Table 1** shows the demographic data of the population within the census tract that contains the mill facility.

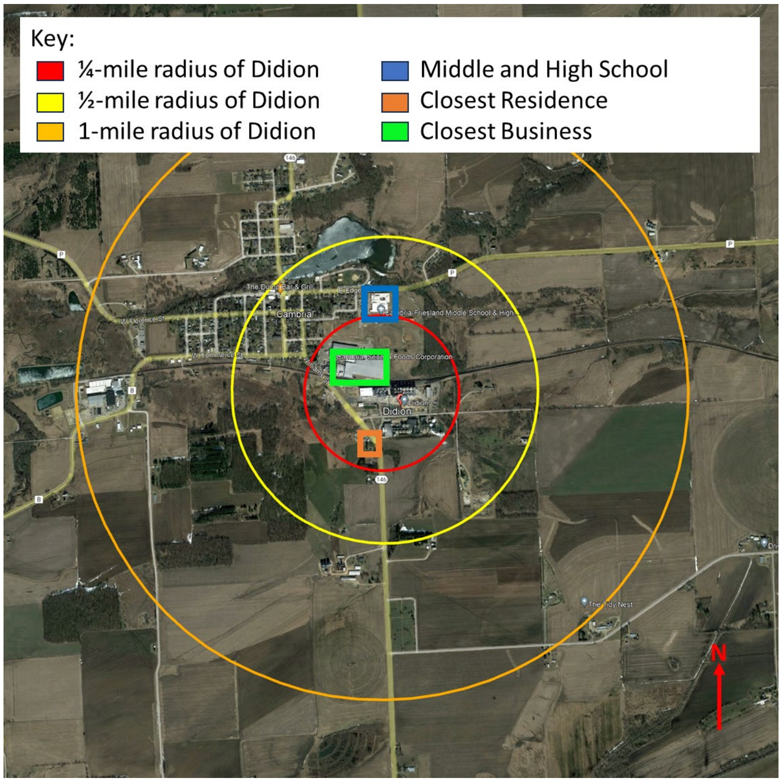

Figure 2: Satellite imagery of Didion's vicinity in 2017. (Credit: Google; CSB)

Table 1: Demographic data for population adjacent to Didion. [a] (Credit: Census Reporter) [2]

Population	Median Age	Race and Ethnicity	Per Capita Income	Percentage of Persons below Poverty Line	Number of Housing Units	Types of Structures
3,925	**40.1**	**93.0% White** **5.0% Hispanic** **1.0% Multiple**	**$30,208**	**8.5%**	**1,633**	**91% Single Unit** **6% Multi-Unit** **3% Mobile Home**

1.1.2 Post-Incident Reconstruction

The incident at Didion was estimated to have caused $15.37 million dollars in property damage. Following the incident in 2017, the mill facility was reconstructed, and production started in 2019. The reconstructed mill facility is shown in **Figure 3** below.

[a] The information provided in Table 1 is generated from the 2020 data of census tract 9701, Columbia County, Wisconsin, which includes the town of Cambria, Wisconsin. [2]

Figure 3: Reconstructed Didion mill facility. (Credit: Didion) [3]

1.2 Combustible Dust Hazards

The grain industry is one of several industries affected by combustible dust fires and explosions; other affected industries include food and pharmaceuticals, metals, wood, coal, polymers/plastics, and others [4, pp. 37-41] [5, pp. 42-44]. In the 2017 edition of the National Fire Protection Association (NFPA) guidance NFPA 61, *Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities*, agricultural combustible dust is defined as:

> Any finely divided solid agricultural material that presents a flash fire hazard or explosion hazard when dispersed and ignited in air [6, p. 8].[a]

Dust combustibility can be influenced by various properties such as moisture content, particle size, and particle size distribution. The ignition of combustible dust will result in a deflagration [7, pp. 10-11]. A deflagration is a propagating reaction which propagates spatially through the reaction mass, such as a combustible dust, that moves slower than the speed of sound [7, pp. 10-11]. Three examples of combustible dust deflagrations are fires, flash fires, and explosions.

Combustible Dust Fires

All fires require fuel, oxygen,[b] and an ignition source to form what is known as the "fire triangle," which is shown in **Figure 4** below. When pneumatically conveying materials, the motive air is the oxidizing agent within the process. The combustible dust serves as the fuel for a potential fire. There are diverse potential ignition sources of combustible dusts [8, pp. 26-28, 72, 75-77].

[a] For the remainder of this report, the term "combustible dust" will be used for either definition of combustible dust or agricultural combustible dust.

[b] While oxygen is typically the oxidizing agent in the combustion reaction, other chemicals can act as oxidants to support the combustion reaction. [44]

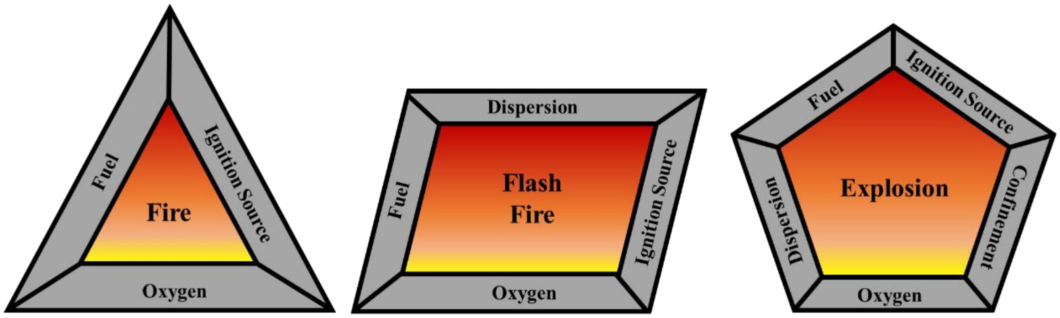

Figure 4: Fire triangle, flash fire quadrangle, and dust explosion pentagon. (Credit: CSB, modified from Crowl [7, p. 13])

One example of a fire involving combustible dust includes smoldering, which can occur under certain conditions. Combustible dust smoldering is a flameless, incomplete combustion process that has been demonstrated in agricultural grain dusts, food ingredient dusts, wood dusts, and coal dust.

> The two most common causes of smoldering fires […] are (1) self-heating that results in spontaneous combustion and (2) the transport of a burning ember generated during material processing [9, p. 6].

A smoldering fire can be difficult to identify until it transitions to a larger flaming fire, which can further transition to a flash fire or explosion [10, p. 183].

Combustible Dust Flash Fires

A flash fire results from a dust cloud igniting without sufficient confinement, and therefore no rise in pressure as an explosion would have [10, pp. 6, 20]. Thus, the "flash fire quadrangle" in **Figure 4** is the result of a "fire triangle" when the fuel is dispersed in the air.

To become a flash fire hazard, combustible dust must be dispersed into the air and exposed to an ignition source. The flash fire hazard severity depends on dust deposit size, location, potential for becoming dispersed, the presence of personnel in the area, and nature of work activities in the area [10, p. 20]. If the dust deposit is located overhead, the hazard may be greater because of the ease with which a disturbed deposit can become a suspended cloud [10, p. 20]. "The hazards of a combustible dust flash fire are flame engulfment or contact, radiant heat, and direct contact with burning particles [10, p. 20]."

Combustible Dust Explosions

Dust explosions additionally require some degree of confinement and dispersion, thus constituting the "dust pentagon" [11, p. 11] [4, pp. 3-4], which is shown in **Figure 4**. An explosion can be described as "a rapid or sudden release of energy that causes a potentially damaging increase [12, p. 771]." The NFPA defines an explosion as "the bursting or rupture of an enclosure or a container due to the development of internal pressure from a deflagration [13]."

A primary dust explosion can occur within the process equipment. Production material or dust, as the fuel source, may be dispersed within the confines of associated process equipment, and thus needs only a process deviation introducing an ignition source, which can result in a fire within the process equipment and lead to a primary dust explosion [11, pp. 22-23].

Secondary dust explosions, external to process equipment, frequently follow primary dust explosions and tend to lead to catastrophic failure of equipment, buildings, etc. [14, p. 271] [4, pp. 23-24]. Once the primary dust explosion occurs, the energy released may be capable of producing a small pressure wave that may knock fugitive dust loose, thereby dispersing it. Due to the confinement and quantity of energy that may be released through the combustion of even small amounts of fugitive dust, the secondary explosion has the potential to significantly damage or destroy facilities [11, pp. 22-23].

Flame Front Propagation

When a deflagration generates a flame that spreads throughout the process equipment, it is referred to as flame front propagation. "Flame fronts from a deflagration can propagate through connecting ductwork to other unprotected process equipment and to the building from outside process equipment [15, p. 57]." The NFPA describes the potential for the entrainment of combustible dust that can result in further ignition and propagation throughout the system.

> The driving force pushing the dust away from the point of initiation […] can easily overcome the force of normal system flow [...] Furthermore, the velocities produced by the deflagration usually greatly exceed those of the pneumatic conveying system under normal design conditions. Consequently, unburned dust and the deflagration flame front can be expected to propagate upstream through ductwork from the locus of the initial deflagration [15, p. 58].

Figure 5 provides a schematic of the propagation of a dust deflagration through a pipe and re-entrainment of settled materials, as described by NFPA.

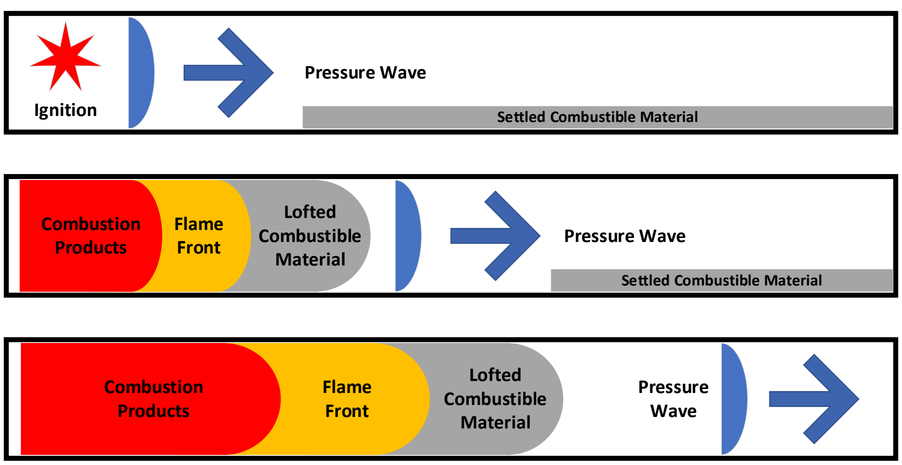

Figure 5: Schematic of propagation through ducting and entrainment of settled materials. (Credit: CSB, modified from NIOSH [16])

As a result of the pressure wave propagating through the equipment, the phenomenon of pressure piling can occur in downstream equipment. Pressure piling is defined as "an increase in pressure within a process due to a deflagration. The pressure wave moves ahead of the reaction front, compressing the unreacted gas and increasing the reaction rate of the following reaction front [17].” The increase in pressure can rapidly exceed the strength of the equipment and cause an explosion due to the rupture of the equipment.

1.3 Combustible Dust Requirements

1.3.1 OSHA Grain Handling Facilities Standard, 29 CFR § 1910.272

While the Occupational Safety and Health Administration (OSHA) does not maintain a general combustible dust standard, OSHA’s *Grain Handling Facilities Standard*, 29 CFR § 1910.272, includes regulations for combustible dust hazard management for the grain handling industry specifically and applies to Didion [17]. The standard contains requirements regarding grain handling-specific operations [17]. These requirements include:

- Development of Emergency Action Plans
- Employee Training of Dust Hazards
- Hot Work Permitting
- Contractor Safety
- Housekeeping
- Installation and Location of Filter Collectors
- Development of Preventive Maintenance Program

The standard also includes several appendices to provide additional information and explanations of the requirements of the standard. *Appendix A* provides examples and explanations of means to achieve each of the performance goals of the standard; however, these examples are not required to be implemented. *Appendix B* states that if a facility maintains compliance with listed NFPA standards, a facility will be considered compliant with the OSHA standard [18]. *Appendix B* lists consensus standards NFPA 61 (B, C, and D),[a] NFPA 66, NFPA 68, NFPA 69, and NFPA 91, which were the NFPA standards available at the time the OSHA standard was published. The appendix does not clarify whether other additional standards are required [18]. *Appendix C* provides a list of references to aid in the implementation of the requirements of the standard [18].

1.3.2 National Fire Protection Association

The NFPA generates consensus standards for fire, electrical, and related hazards [19] [20]. NFPA standards include extensive guidance regarding protection against fires and explosions in combustible dust facilities, among other hazards impacting fire protection.[b] While OSHA provides requirements on managing operational practices and process controls to protect workers, NFPA’s guidance includes more in-depth operation practices

[a] Prior to the publication of NFPA 61 in 1995, the standard was previously separated into four different standards (i.e., NFPA 61A, NFPA 61B, NFPA 61C, NFPA 61D) [23, p. 1].

[b] The NFPA is developing a consolidated consensus standard to combine all the combustible dust requirements into one overarching standard. This draft standard, called NFPA 660, *Standard for Combustible Dusts*, is in the development and public comment stages and is planned to be published in 2024 [87].

and operational controls, as well as building structural guidance not found in 29 CFR § 1910.272, *Grain Handling Facilities Standard*.

NFPA 1 *Fire Code* is the umbrella document that guides users to other NFPA standards related to the risks and hazards associated with a facility [21]. NFPA 1 Chapter 40 *Dust Explosion and Fire Prevention* directs the facility toward applicable standards, such as NFPA 652 *Standard on the Fundamentals of Combustible Dust* and, as applicable, industry- or commodity-specific standards, such as NFPA 61 *Standard for the Prevention of Fire and Dust Explosions in Agricultural and Food Processing Facilities* [21, p. 40.1.1]. The NFPA provides a summary background of the combustible dust standards in NFPA 652 (edition), stating:

> NFPA 652 *Standard on the Fundamentals of Combustible Dust* provides the general requirements for management of combustible dust fire and explosion hazards and directs the user to NFPA's industry- or commodity-specific standards, as appropriate […]. This new standard establishes the relationship and hierarchy between it and any of the industry- or commodity-specific standards, ensuring that fundamental requirements are addressed consistently across industries, processes, and dust types.
>
> While NFPA has addressed combustible dust hazards and safeguards for flour and pulverized fuels, such as coal, as far back as 1920, […] Those documents apply broadly to varied facilities, processes, equipment types, and dust types to protect against the hazards from combustible dust fires and explosions.
>
> A basis for safety embedded in each of those standards requires the fuel—in this case dust—to be managed, ignition sources to be controlled, and impact from an explosion to be limited through construction, protection, isolation, and housekeeping [22, p. 1].

The commodity-specific standards, such as NFPA 61, may further refer the facility to additional applicable standards, such as NFPA 68 *Standard on Explosion Protection by Deflagration Venting* [6, pp. 7, 17-25, 31, 42, 44-46]. **Figure 6** illustrates an example of these relationships.

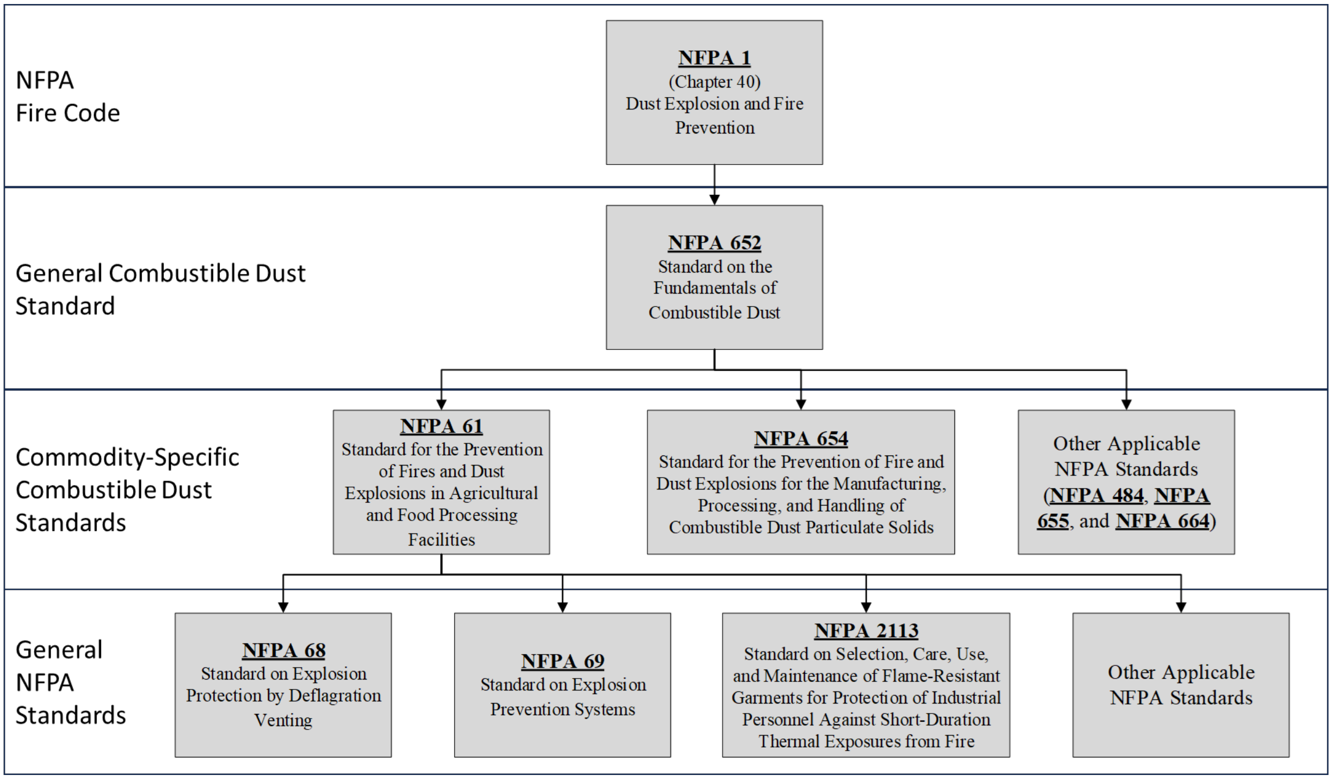

Figure 6: Example of an NFPA standards flow diagram. (Credit: CSB)

As recently as 2015, the NFPA began to incorporate elements of risk management best practices into combustible dust-related standards by requiring a Dust Hazard Analysis (DHA) [22]. The DHA is akin to the Process Hazard Analysis (PHA) requirement in the OSHA 29 CFR § 1910.119 *Process Safety Management* (PSM) *Standard*, but it is specifically designed around the risk management of combustible dust hazards [8]. NFPA 61 incorporated the DHA requirement in its 2017 revision and outlined conducting a DHA in Chapter 7 with only limited guidance [23]. NFPA 61 limited the application and performance of a DHA to bucket elevators, conveyors, grinding equipment, spray dryer systems, and dust collection systems to be completed within a five-year period [6]. However, since the 2017 edition of the standard, NFPA 61 includes *Annex F*, which provides a DHA checklist. This checklist provides detailed and specific guidance for DHA completion [23]. NFPA 61 explicitly requires completion of a DHA retroactively if a facility was built before the requirements took effect, as was the case for Didion [23].[a]

Another consensus standard, NFPA 654, *Prevention of Fire and Dust Explosions from Combustible Particulate Solids*, applies to "…all phases of the manufacturing, processing, blending, conveying, repackaging, and handling of combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire or explosion hazard [24, p. 4]." This standard is applicable to industries that handle combustible dust, except for those industries governed by commodity-specific standards, such as agricultural and food commodity industries. The commodity-specific standards can refer to NFPA 654 for specific requirements, such as pneumatic conveying.

[a] To date, the *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not require a DHA for compliance [17].

1.3.3 State of Wisconsin

State building codes regulate the design and construction of building structures within their jurisdiction. States may write their own code regulations or elect to adopt existing codes and standards by reference, such as the International Building Code (IBC). States can adopt a building code model entirely or pick and choose parts of a given model as they see fit. State fire codes require protections against fires and explosions and often incorporate protection against combustible dust. The IBC incorporates its own fire code, which is the International Fire Code (IFC). Chapter 22 of the IFC, *Combustible Dust-Producing Operations,* incorporates NFPA combustible dust standards by reference [25]. Alternatively, states may choose to adopt NFPA standards directly within the state codes or by reference. Adoption of NFPA requirements is typically via the NFPA 1 *Fire Code* standard, which is the overarching standard that provides guidance on the applicability of subsequent NFPA standards. Some portions of NFPA codes are adopted through the building codes.

The Wisconsin State Commercial Building Code applies to all commercial and industrial building structures in the state of Wisconsin [26]. Wisconsin applied a state-specific Wisconsin Commercial Building code before adopting the NFPA, IFC, and IBC standards.

The Wisconsin Administrative Code first adopted the IFC and IBC in 2001. The Wisconsin Administrative Code uses the IFC and IBC standards for the design requirements of structures at the time of construction. Buildings constructed before the adoption of a given edition of the IFC and IBC standards are grandfathered unless significant alterations are made to the facilities. The Wisconsin State Building Code first adopted NFPA standards applicable to combustible dust in 2008, when Wisconsin adopted the 2009 edition of NFPA 1. Wisconsin adopted this standard after many of Didion's mill structures impacted by the incident were built. The Wisconsin Administrative Code adopted NFPA 1 and adopts the use, operations, and maintenance requirements of the standards for all structures regardless of the date of construction.

1.3.4 Other Guidance

Several industry associations provide safety training resources for combustible dust hazard awareness and risk management. For example:

The Center for Chemical Process Safety (CCPS) published *Guidelines for Safe Handling of Powders and Bulk Solids* in 2004, and *Guidelines for Combustible Dust Hazard Analysis* in 2017. Both publications are applicable for any facility with combustible dust hazards in any industry [8]. *Guidelines for Combustible Dust Hazard Analysis* includes multiple examples and provides special consideration guidance for existing facilities because of the limiting constraints around modification to existing facility structures [8].

The American Conference of Governmental Industrial Hygienists (ACGIH) has published *Industrial Ventilation: A Manual of Recommended Practice* [27]. The two-volume handbook provides guidance for the design, operation, and maintenance of industrial ventilation for a variety of purposes and needs, including as a protection against accumulation of combustible dust to levels that may exceed safe explosibility limits [27]. The manual provides an engineering design basis for industrial ventilation, and specifically points the reader toward NFPA standards as applicable throughout the industrial ventilation design process [27].

FM Global, a mutual insurance company specializing in loss prevention of highly protected risk properties, publishes several free loss prevention data sheets, *Grain Storage and Milling 07-75*, *Combustion Dust Explosion 07-76*, *Dust Collectors and Collection Systems 07-73*, and *Industrial Exhaust Systems 07-78*.

1.4 THE HIERARCHY OF CONTROLS IN COMBUSTIBLE DUST HAZARDS

The National Institute for Occupational Safety and Health (NIOSH) is a federal agency that conducts research and makes recommendations for the prevention of work-related injuries and illnesses and provides guidance on the concept of hierarchy of controls [28]. The CCPS incorporated the hierarchy of controls and inherently safer design concepts in its book *Inherently Safer Chemical Processes: A Life Cycle Approach*.

Inherently safer design minimizes or eliminates hazards by using process conditions or materials that are less hazardous. Inherently safer design is the most effective of three categories of control in the hierarchy of controls. Inherently safer design concepts can be incorporated into processes and equipment designs through elimination, substitution,[a] minimization,[b] moderation,[c] and simplification.[d] The next category is engineering controls; these are controls that are added to the processes and process equipment to mitigate hazards. Engineering controls can be divided into active and passive controls. Passive engineering controls minimize hazards through process and equipment design without requiring the control to activate to control the hazard. Active engineering controls provide mitigation through the detection of a hazard and the activation of a system to respond to the hazard. Procedural controls use policies, procedures, training, and response that require human interactions with the process to detect, react, and mitigate the hazard [29, p. 13].

Figure 7 shows a compilation of the NIOSH and CCPS concepts of the hierarchy of controls and the effectiveness of the controls implemented to mitigate the hazard.

[a] Substitution is defined as "[replacing] a chemical/material with a benign or less hazardous substance; or replace a process or processing technology with one that is benign or is less hazardous [29, p. 18]."

[b] Minimization is defined as "using or having smaller quantities of hazardous substances [29, p. 18]."

[c] Moderation is defined as "[using] less hazardous or energetic processing or storage conditions, a less hazardous form of a material, or facilities that minimize the impact of a release of hazardous material or energy [29, p. 18]."

[d] Simplification is defined as "design [of] facilities which eliminate unnecessary complexity and make operating errors less likely, and which are forgiving of errors that are made [29, p. 18]."

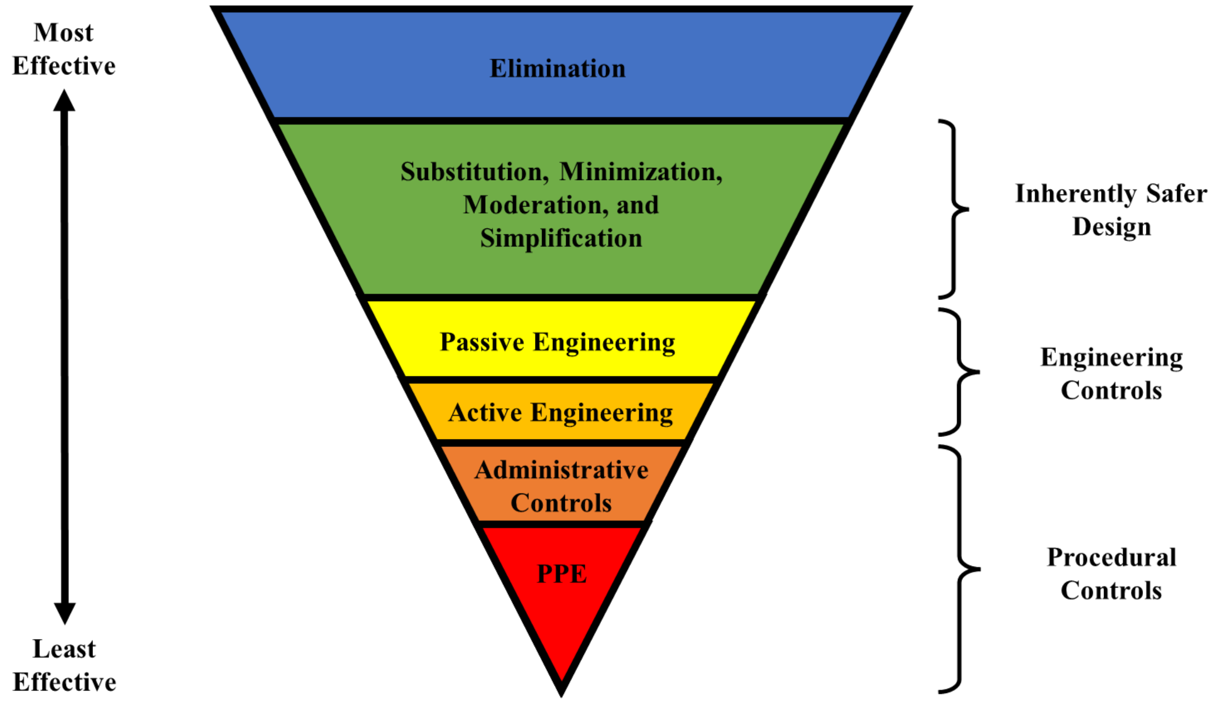

Figure 7: Hierarchy of controls. (Credit: CSB, modified from CCPS [29] and NIOSH [30])

In the context of the hierarchy of controls for combustible dust, it may be impossible to remove the hazard of combustible dust due to the nature of the process(es) involved when handling dust [4, p. 188] [31, p. 299]. According to the NFPA:

> While the specific protection measures vary for each type of dust commodity, the general approach focuses on what is referred to as the three Cs—contain, capture, and clean. You want to first try to contain your dust within your process equipment. Anywhere you can't contain your dust to your process equipment, you want to try and capture it at the point of release with something like a dust collection system. Lastly, anywhere you can't contain or capture it, you want to clean up the remaining dust so it doesn't pose a hazard [32].

Inherently safer design of dust processes includes designing equipment to withstand elevated pressure during deflagrations (**Section 4.3.1.5**). Passive engineering controls that can be utilized with combustible dust processes include deflagration venting and passive deflagration isolation (**Section 4.3.1.2**). Active engineering controls that can be utilized for deflagration control include pre-deflagration suppression, active deflagration isolation, and deflagration suppression (**Section 4.3.1.1** and **Section 4.3.1.3**).

Administrative controls are established work practices that require human interaction to be successful. These controls include fugitive dust management (**Section 4.5**) and management of change (**Section 4.6**). The last line of defense in managing combustible dust and employee protection is personal protective equipment (**Section 4.11**).

2 Process and Incident Description

2.1 Mill Facility Buildings and Layout

Prior to the 2017 incident, the Didion mill facility was comprised of several buildings, which were built as the facility expanded. Each building consisted of multiple floors containing various milling operations. The processes were interconnected to allow for the milling of different types of materials and to meet different customer specifications. Didion's mill buildings were constructed over the course of 20 years, beginning with A Mill in 1991. A Mill, the Boiler Room, and the Multipurpose Building were constructed during the 1990s. B Mill and F Mill were constructed in the early 2000s. C Mill and D Mill were constructed in the early 2010s. **Figure 8** below is a facility map of mill structures prior to the incident.

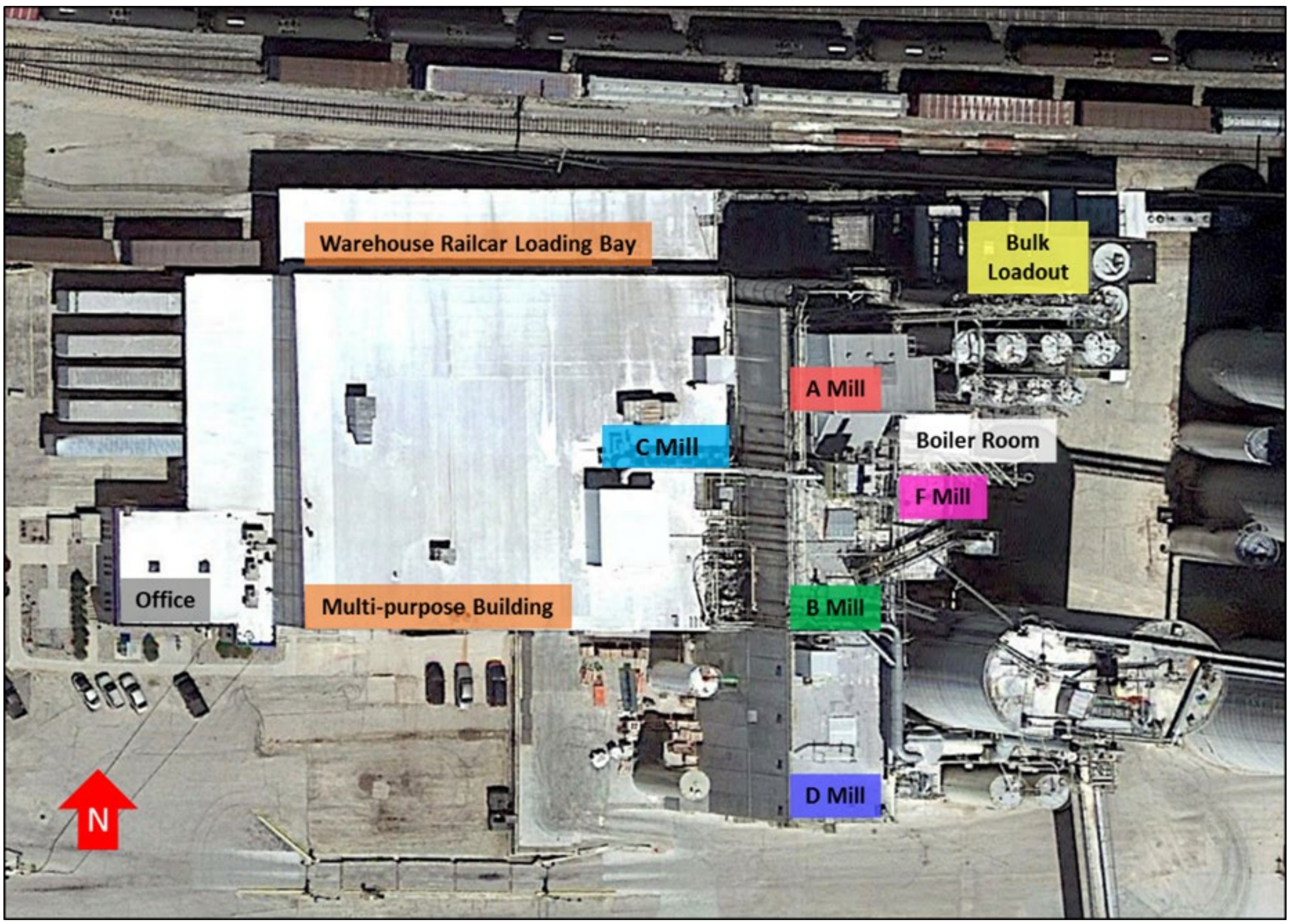

Figure 8: Pre-incident overhead view of the Didion corn mill facility. (Credit: Google Maps 2018; annotations by CSB).

As a shorthand, Didion used the floor number and mill building letter when referring to locations. Thus, the first floor of B Mill was called 1B, the second floor of D Mill was 2D, and so on, although in some cases, the order was flipped, such as B1 rather than 1B. The remainder of this report will use Didion's floor-building shorthand, such as 1B.

Because of all the air handling equipment on each floor of the mill buildings, A Mill and B Mill each had an air makeup shaft that ran vertically through each mill to supply air to the equipment. **Figure 9** shows the location of these air shafts.

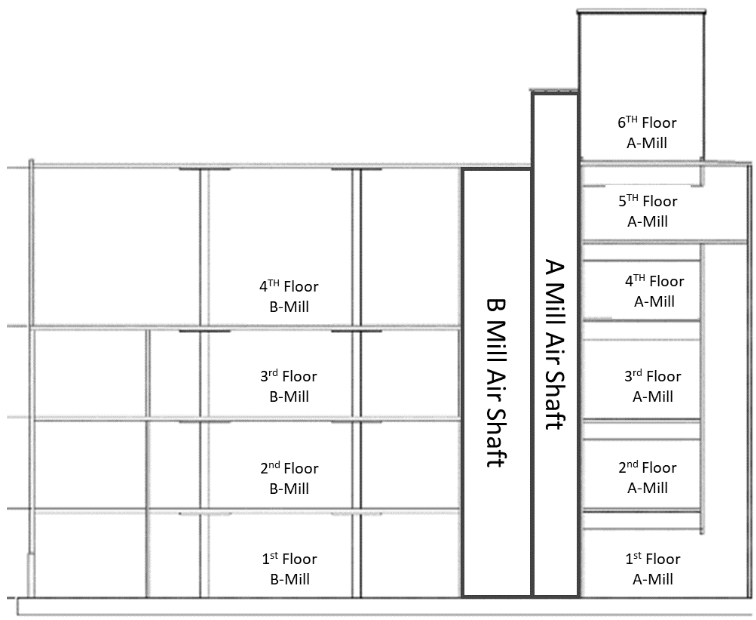

Figure 9: A Mill and B Mill air shafts, shown in bold areas. (Credit: Didion; annotations by CSB)

The mill buildings were interconnected to other structures as the facility expanded, or "add-on construction." For example, as shown in **Figure 8**:

- A Mill shared a common wall with B Mill and a common wall with the Multipurpose Building.
- B Mill shared a common wall with A Mill, a common wall with D Mill, a common wall with F Mill, and a common wall with the Multipurpose Building and C Mill.
- C Mill shared a common wall with B Mill and was housed inside the Multipurpose Building.
- D Mill shared a common wall with B Mill.
- F Mill shared a common wall with B Mill and a common wall with the Boiler Room.
- The Multipurpose Building shared a common wall with both A Mill and B Mill.

2.2 Process Description

2.2.1 Didion Dry Corn Milling Processes

Dry corn milling[a] separates a corn kernel into three distinct components—bran, germ, and endosperm— using process equipment to clean, grind, separate, and convey bulk solids. The process yields a variety of corn products, both food products and non-food additives [33, pp. 270-272, 312] [34, p. 25].

[a] *Engineering Aspects of Cereal and Cereal-Based Products* states, "In the dry milling process of cereals, not only is the size reduction of the grains performed but also the separation of the grain parts according to their composition" [33, p. 98].

Didion received raw corn from local farmers, which was fed to the dry corn mill facility. The facility separated streams by particle size and density. The facility recycled[a] particles that did not yet meet product specification for further particle size sorting and reduction until the final product requirements were met. Didion used different types of mill equipment in the grinding processes, depending on process needs, such as hammer mills,[b] gap mills,[c] and other equipment. Once milling was complete, finished products were stored in a series of bins, from which workers either loaded the products onto trucks and railcars for bulk transportation, or packaged them before shipping.

2.2.2 Processing Equipment in the Bran System

On the night of the incident, problems were first observed in or around the bran system. The bran system received partially processed material from various other parts of the mill, reduced particle size through milling and grinding equipment, sifted material to remove the particles larger than desired, and recycled the larger particles until they reached the desired particle size, which was some of the finest (smallest particle size) material the mill facility produced.

2.2.2.1 Bauermeister Gap Mills

Gap mills are equipment used in several industries, including corn milling, for mechanical impact grinding of non-abrasive solid materials; Bauermeister is a manufacturer of such equipment. **Figure 10** shows a generalized layout for a Bauermeister gap mill interior. As the product and air mixture enters the gap mill, the product accelerates to the rotor outer diameter by centrifugal force and airflow. Product is pulled down through the rotor and grinding baffle and exits at the bottom, where it is pneumatically conveyed[d] to a product receiver.

[a] In this context, recycle loops refer to process streams that are sent back to earlier in the process flow for further processing. For example, particles that are too large can be recycled through milling equipment for further size reduction until they meet specifications.

[b] Hammer mills "consist of ganged hammers (generally rectangular pieces of hardened steel), which are attached to a shaft that rotates at a high speed inside a grinding chamber. The solid material is typically fed by gravity into the mill's chamber and is crushed or shattered by repeated hammer impacts, collisions with the walls of the chamber, as well as particle–particle impacts" [33, p. 104].

[c] A gap mill uses the gap between the rotor and grinding baffle to grind larger bulk solids into smaller bulk solids for control of particle size [33, pp. 98-99, 104-105].

[d] Pneumatic conveying is described below in **Section 2.2.2.2**.

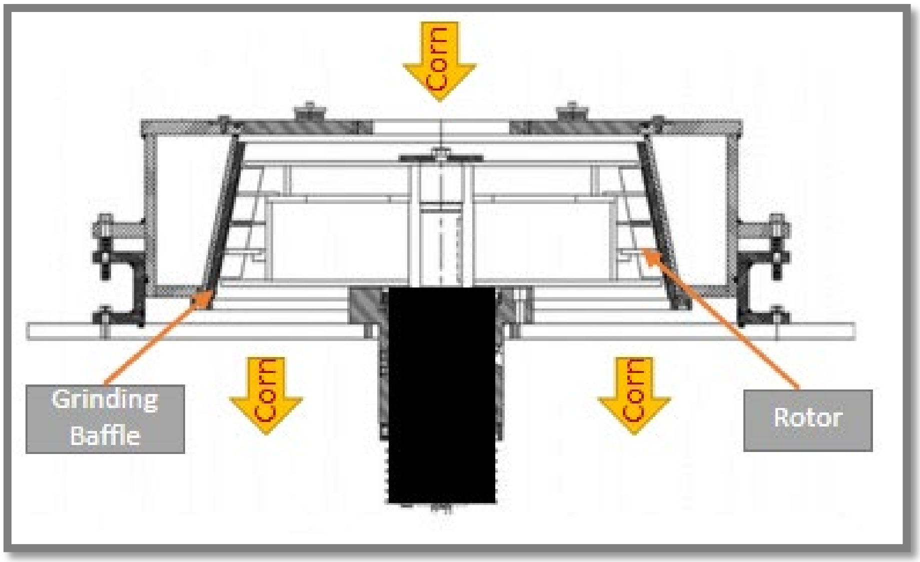

Figure 10: Cross section of a gap mill rotor and grinding baffle. (Credit: Bauermeister; annotations by CSB)

Within the Bran process, Didion employed two Bauermeister gap mills. Didion termed these gap mills the North Bauermeister and the South Bauermeister, after their manufacturer and location relative to each other. The North Bauermeister[a] (North BM) was typically operated with a larger gap between the rotor and baffle, so that it produced larger particles than the South Bauermeister (South BM). The South BM was fed smaller particles and so had a smaller gap. **Figure 11** shows typical product flow through the South BM,[b] including a receiving cyclone, described later in **Section 2.2.2.3**.

[a] The North Bauermeister will be known as the North BM, and the South Bauermeister will be known as the South BM, throughout the remainder of the report.

[b] The North BM has a similar setup as the South BM.

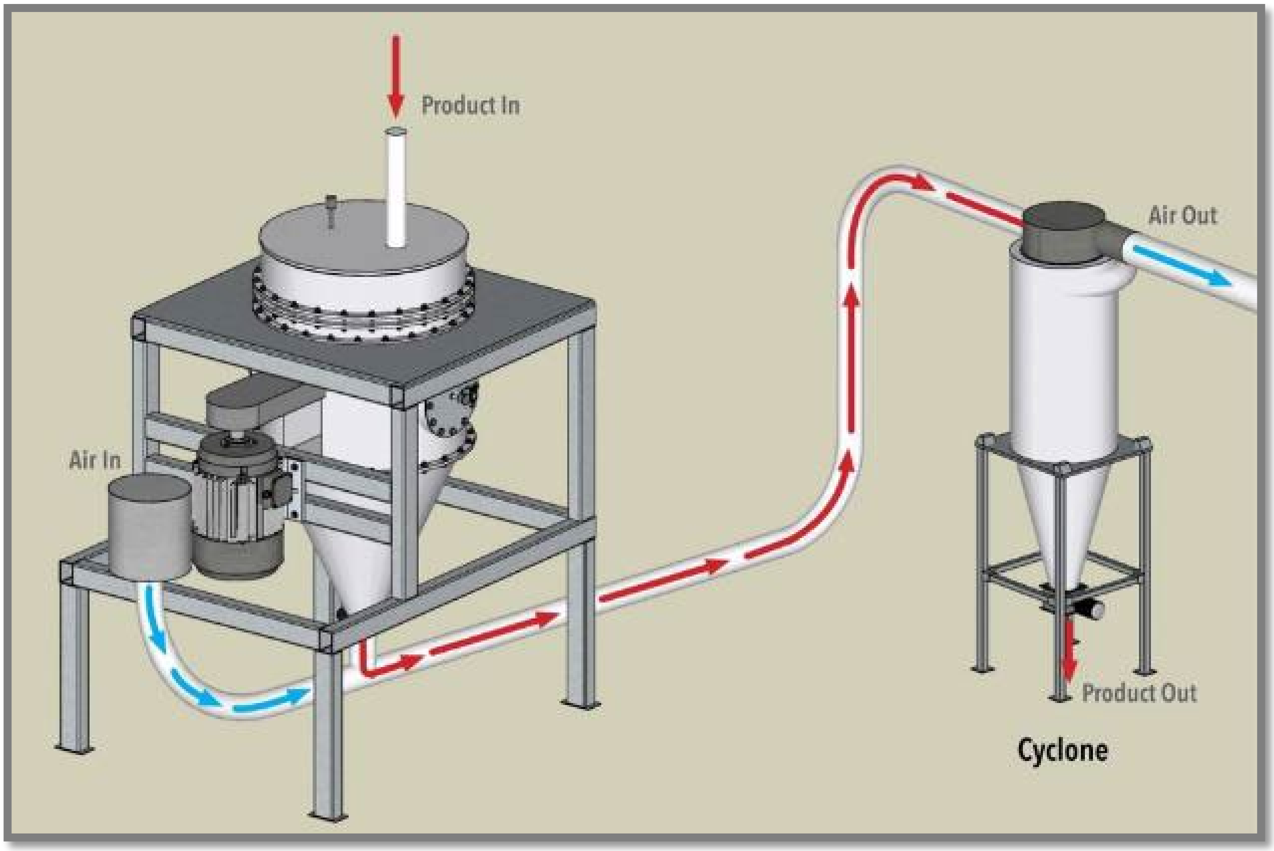

Figure 11: Diagram of South gap mill (South BM) and South BM discharge cyclone. (Credit: CSB)

2.2.2.2 Pneumatic Conveying Equipment

Once product exits any grinding equipment, it is typically pneumatically conveyed to a product receiver such as a cyclone. Didion used several methods to convey product throughout the mill facility from one process step to another. Among these methods was pneumatic conveying.

Pneumatic conveying is commonly used in the industry and involves transporting particulate solids in bulk in a gas stream, in this case air [35, p. 73]. Systems for pneumatic conveying in pipes are classified into two categories: pressure systems and vacuum systems [35, p. 73]. In a pressure system, the air blower is installed upstream and blows air into the system. The pipe is under positive pressure [35, p. 73]. In a vacuum system, the blower is installed downstream and sucks air through the system.[a] The pipe is under negative pressure relative to atmospheric [35, p. 73]. **Figure 12** shows the equipment flow diagram for part of the Bran process, with the vacuum system lines shown in green and the pressure system lines shown in red. Didion's mill facility included both positive pressure and negative pressure pneumatic conveying systems, which is not unusual in such processes.

[a] Fans in vacuum conveying systems are sometimes called "lift fans."

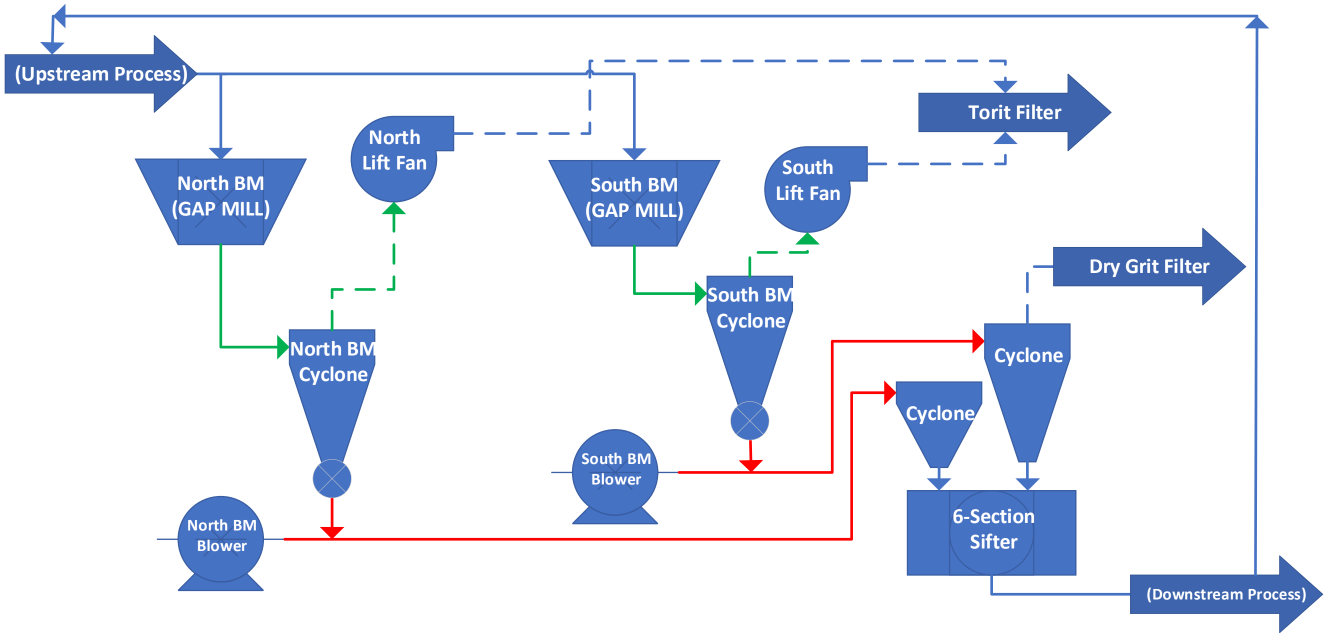

Figure 12: Typical localized bran system process flow for North and South BMs. Vacuum pneumatic conveying lines are shown in green, pressure pneumatic conveying lines in red. (Credit: CSB)

Introducing particulate solids into a system at positive pressure requires special devices [35, p. 73] such as rotary airlocks to seal off the pressurized region from non-pressurized equipment, and to meter product into the pressurized system.[a] The most important design variable in pneumatic transport is air velocity [35, p. 75]. Insufficient air velocity may result in particles settling in horizontal sections and in elbows, tees, and sudden expansion fittings [35, p. 75].

2.2.2.3 Cyclones and Material Transport

Cyclones separate conveying air from the bulk solids being conveyed [35, p. 257]. The conveying air-solids mixture feeds into the top of the cyclone tangentially, then continues to spin [36, p. 709]. Under the effect of gravity and centrifugal forces, the solid particles settle to the bottom of the cone and are usually discharged through a rotary airlock [35, p. 258]. The gas, including very fine particles, commonly referred to as "dust-laden air," is discharged through the exit on top of the cyclone [35, p. 258]. **Figure 13** below gives a visual representation of a cyclone and its process flows as viewed from the side and above [35, p. 258]. A fan may be installed on top of the cyclone to pull the feed mixture into the cyclone from the upstream equipment.

[a] Didion defined an airlock (also known as a rotary airlock, rotary lock, or rotary valve) as a device that acts as a seal between inlet (low pressure) and outlet (higher pressure) ports on equipment, and to aid in metering material into transport piping.

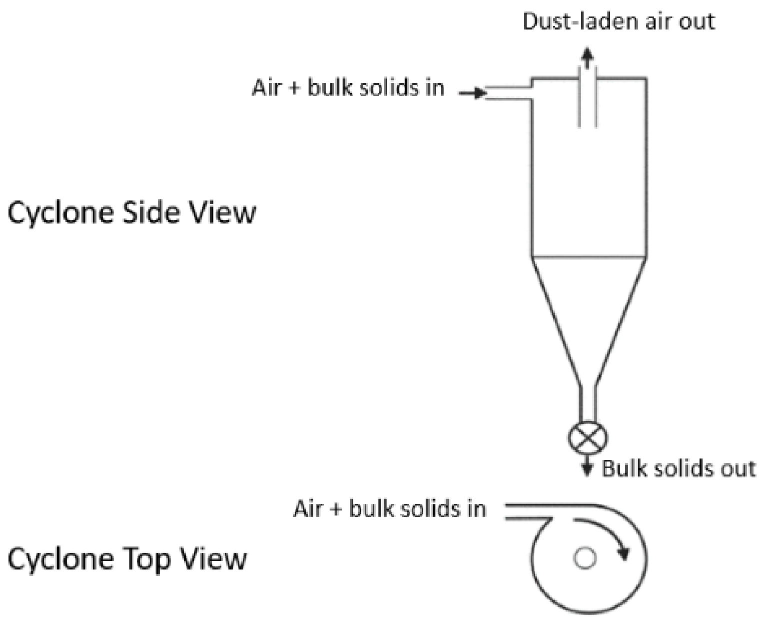

Figure 13: Side and top views of a cyclone separator. (Credit: Burk [35, p. 258])

The North BM and South BM each discharged to a dedicated cyclone nearby. The cyclones each received air and bran particles from their respective Bauermeister gap mills and collected bran in the bottom of each cyclone for transport to the Six-Section Sifter,[a] described below in **Section 2.2.2.4**. The cyclone airflows were each driven by a fan pulling air from the top of the cyclone and bulk solids into the cyclone and discharging the transport air from the top of the cyclone to a dust collector called the Torit Filter, described in **Section 2.2.3.1**. An airlock metered the bran out of the bottom of each cyclone and prevented air pressure from downstream equipment from entering the cyclone. Thus, the Bauermeister cyclones' systems, with fans and airlocks, were examples of vacuum type pneumatic conveying.

Material was transported from the Bauermeister cyclones on 1B to receiving cyclones on 4B. This part of the pneumatic transport was a positive pressure system. Airlocks on the bottom of each Bauermeister cyclone metered bran product into a pipe under the airlock. For each cyclone, a blower pushed the bran under pressure to the fourth floor. Each system had a receiving cyclone just above the Six-Section Sifter to remove the transport air, while dropping product into the sifter (**Figure 12**).

2.2.2.4 Six-Section Sifter

The Six-Section Sifter was a large wooden piece of equipment that separated material by particle size. It was both upstream and directly downstream of the South BM and the North BM due to recycle streams of various particle sizes.[b] In this sifter, a series of moving screens separated the product into several different streams based on particle size. Larger particle-size streams were recycled for more particle size reduction, while desired particle-size streams were sent to product storage or packaging.

[a] Didion defined sifters as mechanical equipment separating particles based on particle size using screens of varying sizes..

[b] Several pieces of equipment and multiple processes recycled through the Six-Section Sifter.

2.2.3 DUST COLLECTION EQUIPMENT

Size reduction equipment also produces undesired smaller particles, or dust [37, pp. 21-22]. Dust-laden air inside equipment could not be vented to the atmosphere[a] without first going through a dust collector, such that only clean air was ejected to the atmosphere [36, pp. 709-711]. At Didion, products in the desired particle size range were sent to product storage bins as discussed above in **Section 2.2.1**, but the dust was collected as described below.

The facility contained several dust collection systems due to the inherently dusty process. Air used for pneumatic conveying contained corn and dust particles and required filtering before the air exited the process to the environment [36, pp. 709-711]. Many of these dust collection systems were called bag filters, or baghouses, a particular type of dust collector [36, p. 711]. A baghouse typically consists of tube-shaped filter media bags (elements)[b] supported by wire cages inside a larger chamber [38, p. 30.14]. Dust-laden air enters near one end of the chamber (usually the bottom), and the air flows through the filter media bags. Dust is trapped on the outside of the bags, and the clean air flows through the bags and exits at the other end (usually the top) of the chamber [36, p. 711]. **Figure 14** illustrates this baghouse dust collector operation.

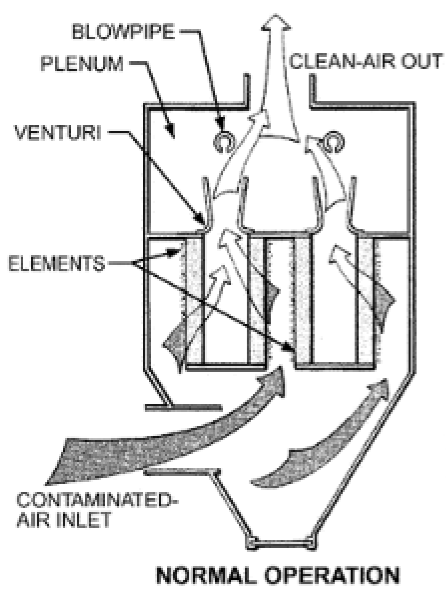

Figure 14: Example of baghouse-type dust collector operation. (Credit: ASHRAE [38, p. 30.14])

2.2.3.1 Torit Filter

The Torit Filter was located in 2F. The Torit Filter collected dust from a variety of equipment from A Mill, F Mill, Bulk Loadout, and some equipment in B Mill. The North and South BM Cyclone Lift Fans on 1B sent conveying air to the Torit Filter for dust collection. Although the Torit Filter had paper-like cartridges to filter

[a] Dust-laden air typically must be filtered before release to the atmosphere in order to meet environmental regulations [36, p. 709].

[b] Most baghouses use flexible cloth or other fabric-like materials of construction for their filter media, although rigid cylindrical cartridges could also be used, made of similar fabrics [38, p. 30.10]. Throughout this report, the CSB refers to all these materials and filter elements collectively as "filter media bags" or "filter media elements".

dust rather than flexible bags as described above for baghouses, the operating principle is the same as described above in **Section 2.2.3**.

2.2.3.2 Dry Grit Filter

The Dry Grit Filter was one of the largest dust collectors at the facility, approximately 50 feet tall and was 15 feet in diameter. The Dry Grit Filter was located outside the mill buildings, east of D Mill, due in part to its large size. The Dry Grit Filter was a baghouse-type dust collector that operated as described above in **Section 2.2.3** and collected dust from most of the equipment in B Mill and D Mill Bran systems, along with other equipment throughout the mill facility. According to Didion's drawings, at least 46 pieces of equipment throughout the mill facility connected to the Dry Grit Filter. Based on photographic evidence and drawings from Didion, the receiving cyclone on 4B associated with the South BM also vented to the Dry Grit Filter.

2.2.4 Incident Impacts

The incident occurred during the night shift, fatally injured five employees, and injured the 14 surviving employees on-site at the mill facility. The facility maintained only limited staffing at night compared with the day shift, which typically had approximately 96 employees on site. Of the five fatalities, two occurred from fire-related injuries and three from crush or blunt force injuries. Three other victims received burns in the incident. One employee was seriously injured and suffered a double amputation. The other employees suffered from burns and impact injuries. The incident did not result in any known off-site impacts to the area surrounding the Didion mill facility.

2.2.5 Key Equipment Locations and Connections

The equipment in the Bran process, as described in **Section 2.2.2**, had the potential to make products using different equipment configurations. However, at the time of the incident, a temporary change was in place that changed the configuration by connecting the North BM and South BM Cyclones together using a common transport line to 4B in an effort to increase bran production rates. This temporary change setup is shown in **Figure 15**. The temporary connection is shown by a red line.

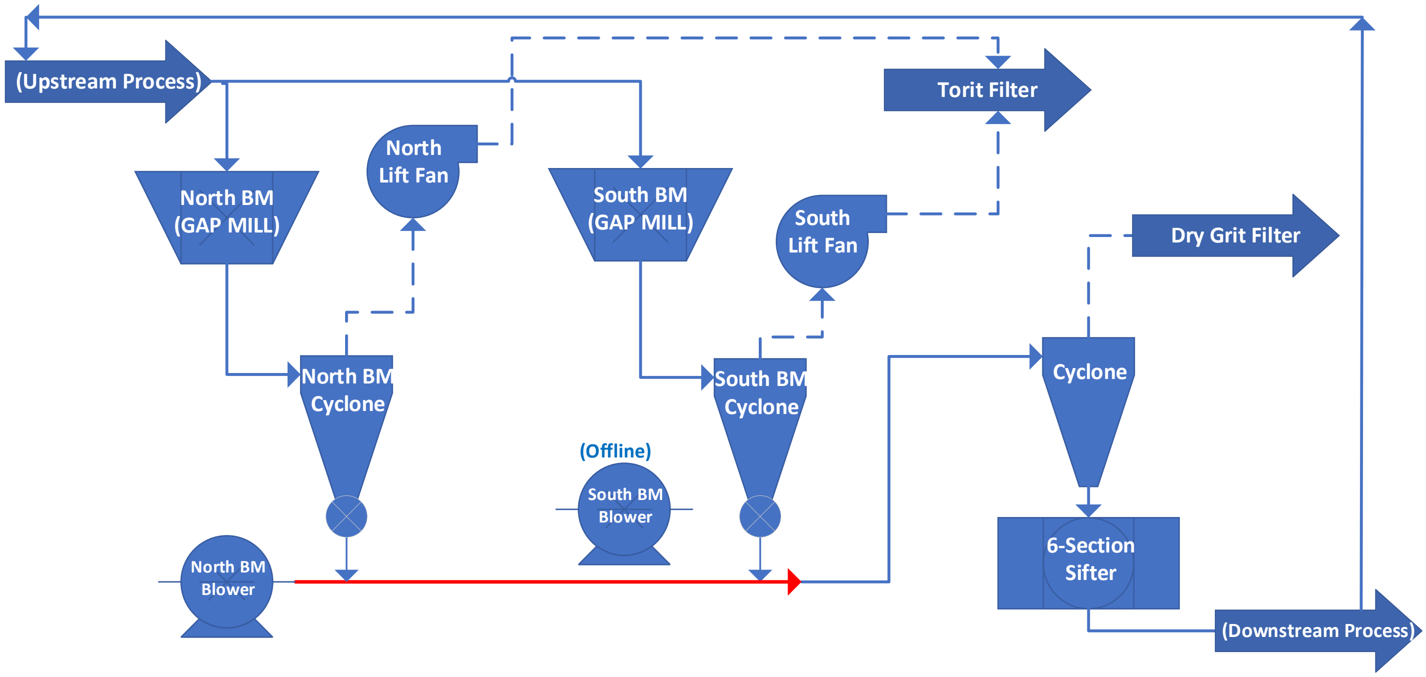

Figure 15: Temporary localized process flow when incident occurred. The red line shows the temporary connection. (Credit: CSB)

2.2.5.1 Mapping Process Flow

The relative locations of the equipment discussed above in **Sections 2.2.2** and **2.2.3** are shown in **Figure 16**. As noted above, the North BM and South BM, their receiving cyclones, and lift fans were in 1B. The downstream receiving cyclones and the Six-Section Sifter were located in 4B. The Torit Filter was in 2F, and the Dry Grit Filter was located outside, just east of D Mill.

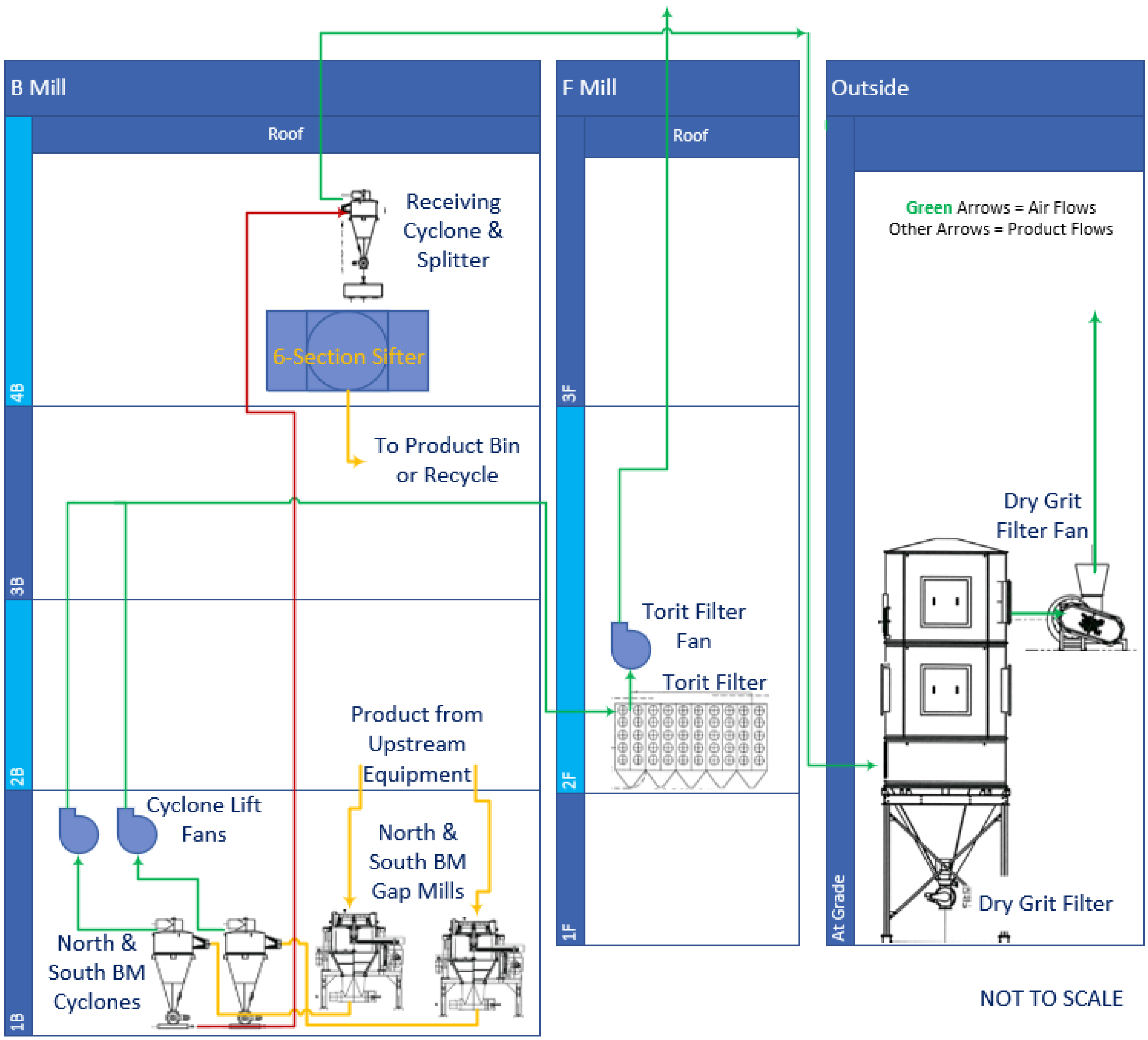

Figure 16: Relative locations of Bran process equipment and dust collectors. (Credit: CSB)

2.3 Event Sequence

2.3.1 Observations of Smoke

On May 31, 2017, around 10:30 p.m.,[a] multiple employees throughout the mill facility noticed an unusual smell or saw smoke. Some employees noted “it smelled like smoke,” or “I saw a bit of smoke, but I didn’t see exactly where it came from.” Smoke was first observed just outside B Mill, wafting out the northeast door of 1B, and in

[a] Throughout the remainder of this report, all times listed are local times, which is Central time.

the center loading bay, just east of A Mill. Several employees searched throughout A and B Mills, trying to pinpoint the source of this smoke, believing the smoke was coming from a piece of equipment in A or B Mill.

After searching for approximately 15 to 25 minutes, five employees converged in 1B and together continued to search for the smoke source. On entering 1B, an employee noted, "[a]s soon as I opened the door, I saw lingering, really thin smoke on the ceiling." The employees investigated 1B by feeling equipment for hot spots and looking for plugged equipment where visible. The smoke "was just too thin to tell where it was coming from" according to one employee.

Eventually, only two employees, Employee A and Employee B, remained in 1B continuing their search. Employee A was examining flow in the South BM Cyclone to ensure there was no obstruction. Employee B was observing a different piece of grinding equipment to determine whether it was the source of the smoke. Neither had identified any smoke sources or abnormalities, but suddenly, both employees were startled by a loud noise coming from the South BM area. Neither employee was directly observing the South BM initially, but both turned to it immediately.

2.3.2 Initial Fire and Explosion

Immediately after the loud noise (Explosion 1), Employee A noticed dust and smoke coming out of the South BM area. Employee B observed the inlet air filter pop off the product conveyance piping associated with the South BM discharge as shown in **Figure 17**, stating, "I saw it flying through the air when I turned my head" toward the South BM. He then observed flames coming out of the South transfer line to the cyclone.

> I heard a huge boom. And then a constant…like a consistent roar. […] I looked back and it was like a three- to four-foot flame that was shooting out of the intake of the suction line that takes product from that Bauermeister to the cyclone. […] I just saw fire and it stopped. It blew off and was blowing off for maybe five seconds and then it sucked back in. There was no flame. And then it blew back out like five seconds later.

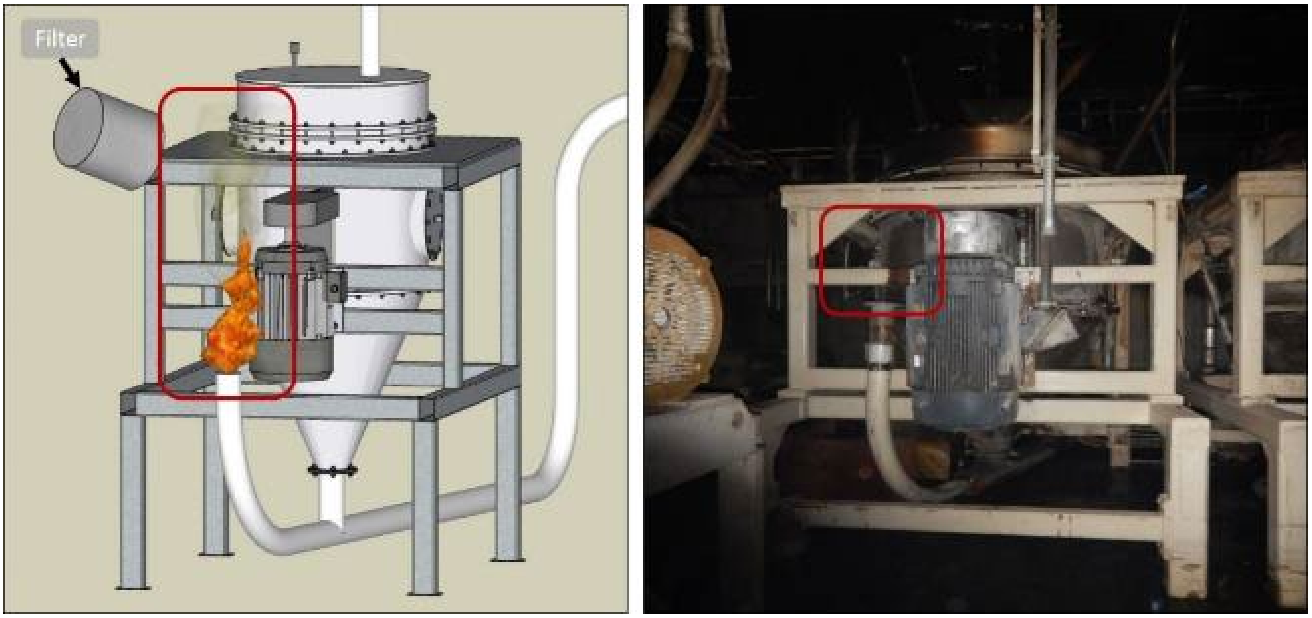

Figure 17: Re-creation of fire observed at Bauermeister air intake filter blowing off (left) and filter missing post-incident (right). (Credit: CSB)

Hearing this loud noise (Explosion 1) and seeing dust and smoke emanating from the South BM, Employee A, who could not understand how product was blowing out of the air intake line, radioed Employee C in the control room to turn off the South BM. In the control room, Employee C responded on the radio that he would shut down the South BM. At the same time, Employee B noted dust "misting down" from overhead piping.

Seeing the flame and dust in the air and recognizing that the dust cloud was likely to ignite and explode, Employees A and B decided to leave 1B immediately. They ran out in opposite directions, each leaving the same way they had entered, as shown in **Figure 18**. As Employee B left 1B, he could still hear radio traffic, but he could not interject on the Miller radio channel to tell people to evacuate due to the amount of radio traffic.[a] Just as Employee B stepped outside, the radio channel cleared. He attempted to make an evacuation announcement, but at that moment, a significant explosion occurred (Explosion 2).

[a] Didion employed several radio channels: one for the Millers, one for packaging operations (known as Pack), and one for Bulk Loadout. Employee B only transmitted on the Millers' channel.

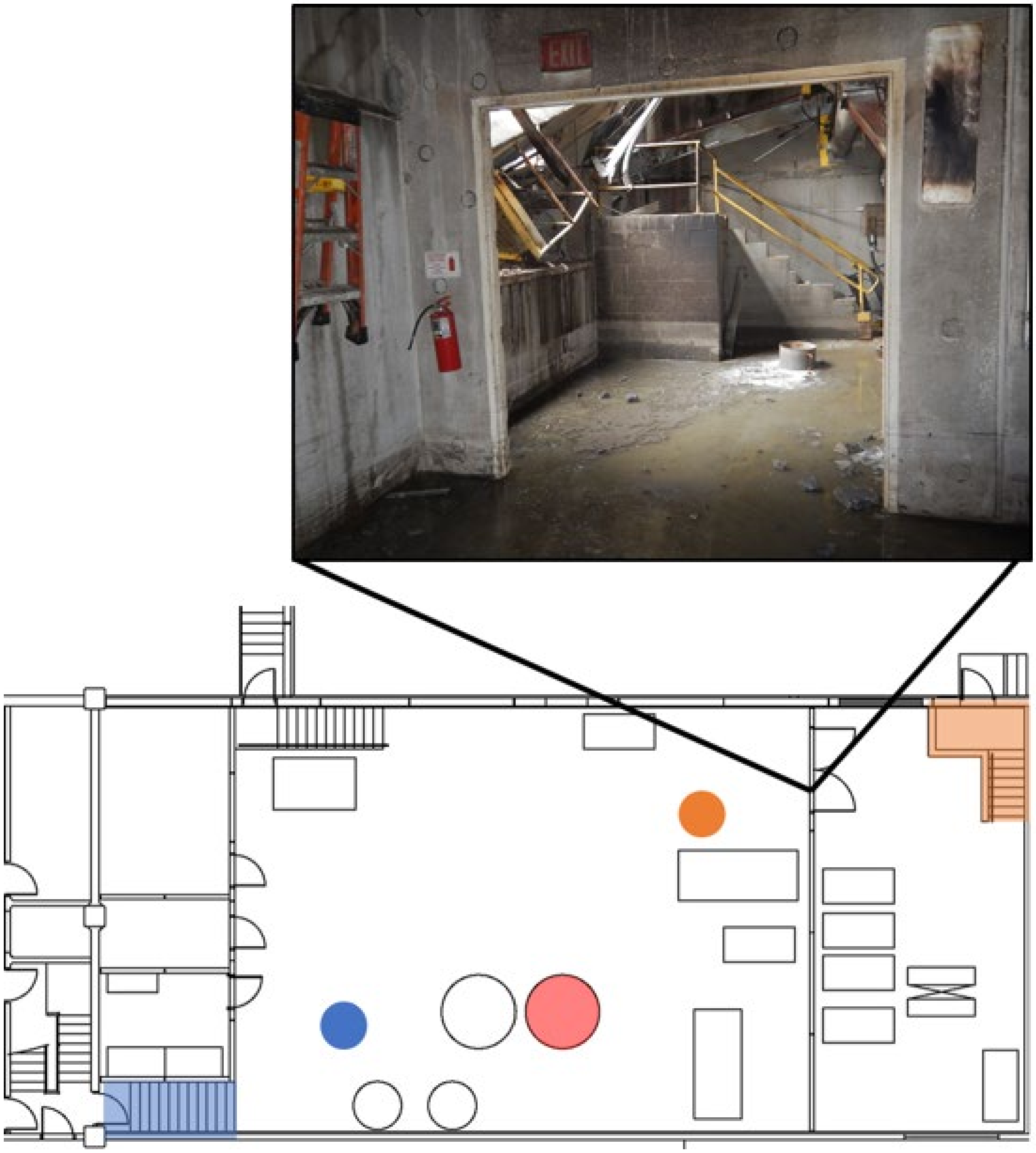

Figure 18: 1B floor plan showing escape routes. Employee A escape route shown in blue and Employee B escape route shown in orange. South BM shown in red. Inset photo: stairwell post-incident that Employee B escaped through. (Credit: CSB)

2.3.3 SECONDARY EXPLOSIONS AND BUILDING COLLAPSE

In the control room, located off a hallway near the 2B entrance, Employee C did not have enough time to turn off the South BM before the larger explosion (Explosion 2) occurred. The explosion was felt throughout the facility.

Employee A was on his way to the control room and was just outside the control room when Explosion 2 occurred. As he turned, he heard the explosion, noting later that, "this is when everything happened"—he felt fire coming from 1B up toward him from the stairwell and heard and felt multiple subsequent explosions. Employee A described the sequence of explosions:

> …the explosion occurred, there was a strong explosion, and I could hear the strong explosion and [I] heard as if the explosion continued... […] a "boom, boom, boom, boom, boom, boom, boom" was heard, and that was all, and the lights went off and I felt the fire and burns.

Employee B also described, as he escaped from the building via the southeast door of 1B, that multiple explosions continued to occur. He estimated that he was 15 to 20 steps outside the southeast door of 1B (see **Figure 18**) when Explosion 2 happened. He was having difficulty seeing his escape route through dust and smoke.

Employee B then described the Dry Grit Filter exploding as he was running past it outside the Mill buildings, trying to escape:

> And then another explosion happened up over the top of me and blew me down to the ground again, like into the wall, the side of the building. And that was from the…I later learned that that was from the big [Dry Grit] filter that's outside. The blast gates[a] blew off of it because the fire must have made it all the way through that suction line, up to the roof, and then sucked itself into that filter.

Once Employee B was clear of the main Mill buildings, he described the continuing explosions occurring within the mill facility.

> …as I was running, I was looking behind me and the whole building was just…there were fireballs and stuff. It just kept exploding. Just sounded like thunder, like constant thunder.

Before either Employee A or B could radio all channels[b] for evacuation, multiple explosions had begun within the mill facility, which immediately led to collapse of multiple mill buildings as the explosions continued to propagate throughout the mill facility. Explosion 2 is estimated to have occurred at 11:00 p.m.

Explosions continued for a time, as Employee B still noted a particularly large fireball even after escaping the buildings, while waking a nearby delivery truck driver in the parking lot to call 911, stating, "There was another huge explosion that happened like right in the center of the mill. It was just a fireball" that he estimated to be over 100 feet high. **Figure 19** shows a timeline indicating the major incident events in sequence.

[a] "Blast gates" was a term Didion used to describe the deflagration vents on the Dry Grit Filter. This will be further described in **Section 4.3**.

[b] Some employees heard an evacuation alert over the radio, but within seconds, the explosions began, and Employee B reported that he did not have time to announce on all radio channels.

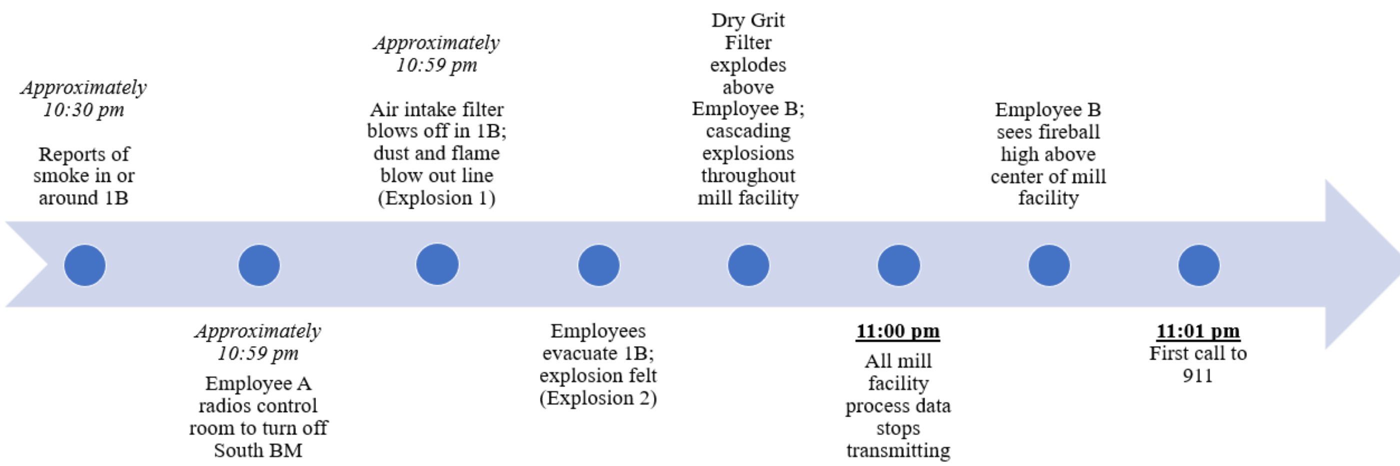

Figure 19: Summary timeline of incident. (Credit: CSB)

2.4 Post-Incident

2.4.1 Mill Facility Damage

After the explosions, the incident scene was found to contain the following:

- Several mill buildings partially or completely collapsed:
    - A, B, and D Mill buildings were severely damaged.
    - The Multipurpose Building (including C Mill), F Mill, and the Boiler Room building were destroyed.
- Evidence of prolonged fire in several parts of the facility.
- Several connected pieces of equipment had internal fire or explosion damage.

Figure 20 and **Figure 21** below show overhead images of the facility after the incident.

Figure 20: Didion Mill following incident. (Credit: Didion)

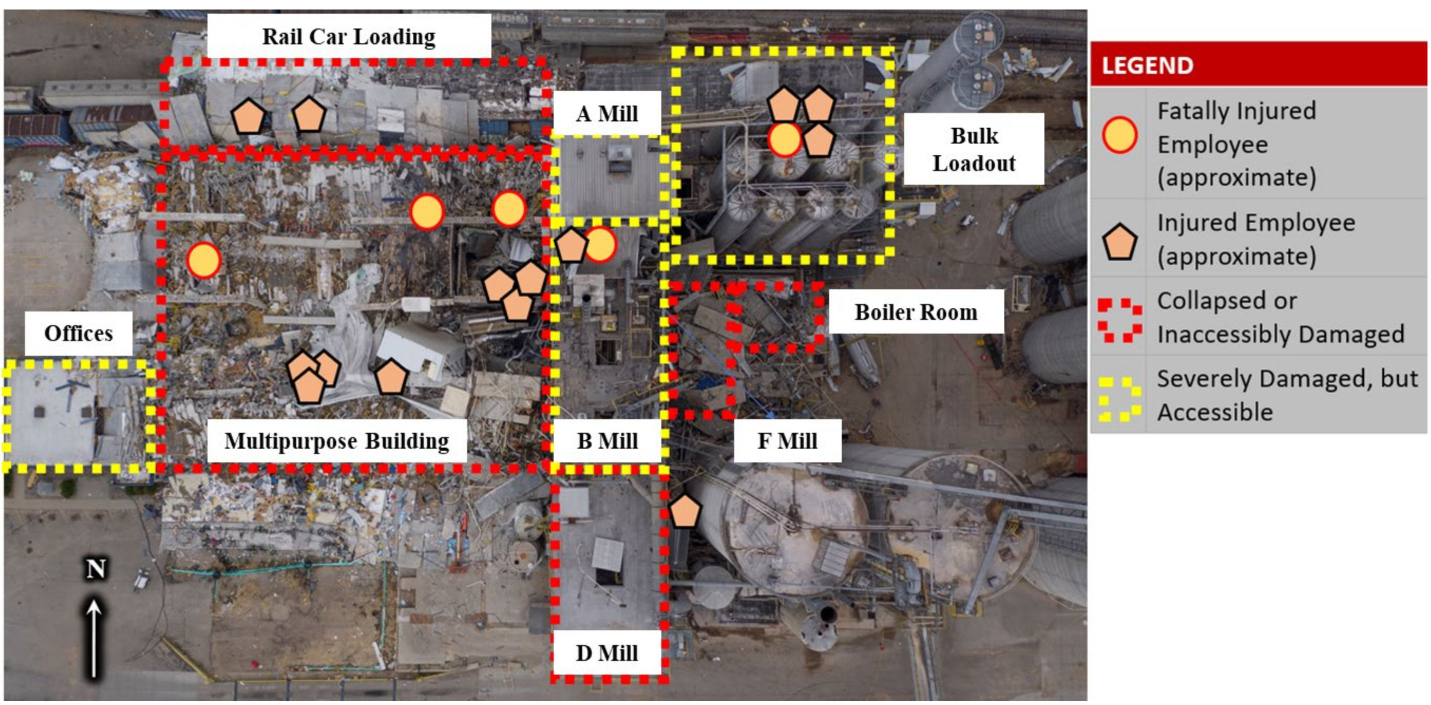

Figure 21: Overhead view of Didion Mill following incident. (Credit: CSB)

B Mill Damage

The B Mill building and equipment sustained a variety of damage, on all floors: fire damage internal to process equipment; fire damage to walls, ceilings, and the exterior of process equipment; fire and structural damage in the B Mill air shaft; and significant structural damage throughout the building. All floors in B Mill contained multiple types of damage.

The heaviest fire damage was at the ground level (1B), particularly on the north end nearest A Mill and the air supply shafts. Several locations indicated fire or explosion damage,[a] both internal to the process equipment and in 1B at large. The North BM and South BM, and their respective cyclones and fans, all exhibited some degree of both internal blackening and external damage, extending to connected process equipment on other floors.

Other B Mill damage included doors blown off hinges or out of frames, and walls and ceilings blackened on multiple floors. Some process equipment on all floors exhibited significant burn damage themselves but were surrounded by undamaged equipment.

Structurally, the 4B east and west wall panels detached from the B Mill structure and fell on top of F Mill, Multipurpose Building, and C Mill rubble. The air intake shaft on 4B buckled in a way that did not occur in A Mill or on any other floor in B Mill. On the south end of B Mill, the floors collapsed and there were some missing wall panels. The south end of B Mill did not have significant fire damage; significant amounts of unburned corn remained there.

Dry Grit Filter Damage

The Dry Grit Filter and its ductwork sustained fire and explosion damage. The Dry Grit Filter blast panels were blown open, and the interior was completely burned. The Dry Grit Filter supply ductwork also indicated evidence of a sustained internal fire or smolder, as well as ruptures in several locations.

D Mill Damage

D Mill structural damage included a large crack in the east wall, and several walls bowed outward. Photographic evidence indicated that virtually all the interior D Mill damage was internal to the process equipment; there was very little fire damage inside the D Mill building at large. Dust found outside the process equipment in D Mill remained unburned, and another filter approximately six feet from severely burned ductwork, called the 4D filter, was unburned. Equipment connected to the Dry Grit Filter that could be observed showed evidence of internal fire or explosion damage.

Multipurpose Building Damage

C Mill, the packaging areas, and the warehouse were contained in the Multipurpose Building,[b] and all had been on fire in some places, based on photographs. The C Mill and some packaging areas were located on the west side of B Mill and shared the B Mill west wall. There was a sustained fire in this area, which caused severe

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[a] Note that for the purposes of this section, physical damage to equipment likely to have occurred during demolition is not considered "damage." This section specifically is referring to damage resulting from the incident on May 31, 2017.

[b] The Multipurpose Building housed several different functions and operations, including Warehouse, Quality Control Lab, Maintenance Shop, Administrative Offices, Packaging Operations, and C Mill.

damage throughout. Some equipment in this packaging area that connected to the Dry Grit Filter sustained internal fire damage, but the rest of the equipment in the Multipurpose Building was too fire-damaged to assess. The entire Multipurpose Building collapsed, and several 4B west wall panels fell on top of the collapsed C Mill area.

F Mill and Boiler Room Damage

The F Mill building and the adjoining Boiler Room building were located on the east side of the B Mill building. Both buildings completely collapsed, although little fire damage was noted. At least four wall panels on the east side of 4B fell on top of the collapsed F Mill rubble. When recovered after the incident, the two natural gas-fired boilers were found largely undamaged beyond building collapse.

The North BM Cyclone Lift Fan and South BM Cyclone Lift Fan on 1B both discharged to the Torit Filter, as described above in **Section 2.2.2.3**. The Torit Filter was located on 2F. The ductwork on the Torit Filter inlet ruptured at the flanged connections, indicating evidence of internal overpressure. Significant amounts of burned and unburned material were inside the duct. The inside of the Torit Filter indicated some fire damage at the inlet, but the filter interior was largely undamaged.

A Mill and Bulk Loadout Damage

The A Mill area opens out through a passage to the Bulk Loadout area to the east on the lower two levels. These areas were severely blackened and fire damaged. The CSB did not identify any clear evidence in A Mill of internal process damage such as was found in B Mill or D Mill. Equipment external surfaces throughout A Mill exhibited fire damage or fire residue. The vertical air intake shaft in A Mill, as described above in **Section 2.1**, showed significant fire damage throughout.

Structural damage was most obvious on the upper levels of A Mill, particularly at 4A and 5A. There were isolated areas of severe damage at the west exterior wall on 4A and 5A. The concrete wall fractured and bulged outward. On 4A, the wall disconnected from the floor slab.

2.5 Incident OSHA Findings and Citations

Following the incident that occurred on May 31, 2017, OSHA issued 19 citations to Didion Milling relating to both a previous fire on May 29, 2017 (discussed in **Section 4.7.2)**, and the explosion on May 31, 2017. Of the citations, five were "Serious" and 14 were "Willful" violations [39]. **Appendix H** summarizes the citations issued by OSHA, which have been contested by Didion as of the date of this report. These citations include housekeeping, lack of engineering controls, inadequate maintenance of equipment, and lack of adequate personal protective equipment.

2.6 Post-Incident Inspections

Following the incident, both the North BM and South BM and the mill facility structures were independently inspected for evidence of what occurred the night of the incident.

2.6.1 Bauermeister Gap Mills

The CSB commissioned a complete disassembly and examination of both the North BM and South BM in tandem, to inspect their condition, noting similarities and differences.

While the South BM inspection found discolorations inside the equipment that may have been due to smoke or heat, the South BM did not show signs of excessive bearing heating, belt dragging or overheating, direct contact between the rotor and grinding baffle, or clogging. In short, there was no evidence found that could indicate an ignition source inside the South BM. The equipment inspection concluded that while the South BM exhibited mechanical damage consistent with the collapse of mill structural components,[a] the South BM contained fairly limited fire damage, and the damage that did exist was at the bottom of the unit (to be discussed further in **Section 3.1.2**). Other potential sources of ignition could not be eliminated, including potential ignition sources elsewhere in the process, upstream or downstream of the South BM.

At the same time the South BM was inspected, the North BM was torn down and inspected as well. The North BM experienced less severe damage but in a similar pattern as the South BM. The material inside the South BM qualitatively appeared to be burned more completely than the material inside the North BM, with a burned odor not present in the North BM.

Figure 22 and **Figure 23** show the underside of each rotor and the bottom cone (discharge) section interior, respectively. Both the North BM and the South BM showed some burn evidence, but the South was significantly darker and more extensive.

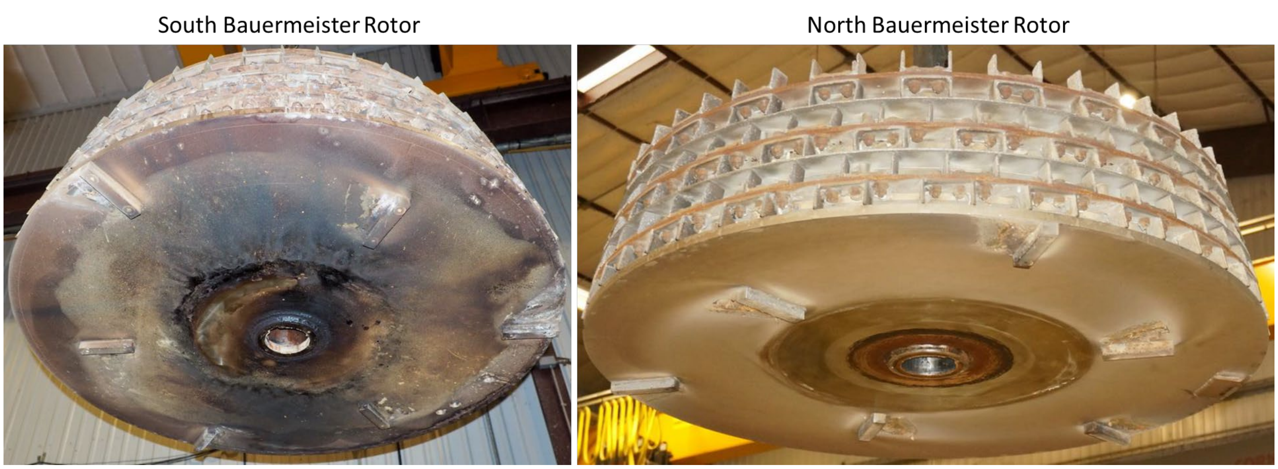

Figure 22: Bottom of gap mill rotors: (left) South BM and (right) North BM. Note greater extent of discoloration on South BM. (Credit: CSB)

[a] The North BM and South BM could not be retrieved for the teardown inspection until after B Mill demolition. The building collapse damage was a natural consequence of the building demolition post-incident and not related to the incident itself.

Figure 23: Bottom interior of gap mills: (left) South BM and (right) North BM. Note greater extent of discoloration on South BM. (Credit: CSB)

2.6.2 Facility Structural Inspection

The CSB commissioned a forensic evaluation of the Mill buildings. Due to the structural damage after the incident, inspectors' access was limited to levels one through three in B Mill (1B, 2B, 3B) and levels one through five in A Mill (1A, 2A, 3A, 4A, 5A) to minimize exposure to potential collapse hazards.

The facility inspection surveyed damage and completed directional fire and blast analyses. Directional indicator analysis conducted at the incident scene confirmed that an initial explosion originated in 1B and propagated upward into the A Mill and B Mill facilities through the vertical air shafts and into F Mill and the Multipurpose Building through openings from B Mill into these areas. The analysis used Computational Fluid Dynamics modeling and calculations as specified in NFPA 68 (2018) to determine this. The analysis found that:

> Propagation of this explosion [in 1B] to other areas of the mill was required to cause the observed damage to other portions of Didion [mill facility] including Levels 2 through 4 of [B Mill], Levels 1 through 5 of [A Mill], the Multipurpose Building, and [F Mill]. Propagation of fire and explosion is consistent with the observed damage, blast directional indicators, and fire directional indicators.

The complete evaluation report is in **Appendix E**.

3 Incident Analysis

The following section discusses the sequence of events during the incident and describes the likely mechanisms involved with the available supporting evidence. The CSB collected the available information, including eyewitness accounts, process trend data where available, and physical evidence found after the incident, and compared them with known phenomena described in research literature. These elements were integral to reconstructing the incident.

3.1 INCIDENT PROGRESSION

The likely incident progression involved a series of events and phenomena, which can be described in these steps:

1. A smoldering nest developed in the Bran process, likely downstream of the South BM.
2. A primary explosion (Explosion 1) occurred inside Bran process equipment, likely located in 1B.
3. The primary explosion propagated inside the interconnected process equipment.

4a. The first secondary explosion (Explosion 2) occurred on 1B.

4b. Within a few seconds of Explosion 2, the Dry Grit Filter overpressured and released a fireball.

5a. A series of secondary explosions begins throughout the mill buildings, resulting in significant building damage and collapse.

5b. At approximately the same time, a deflagration propagated from the Dry Grit Filter back toward other process equipment through piping and ductwork.

Figure 24 below summarizes the series of events.

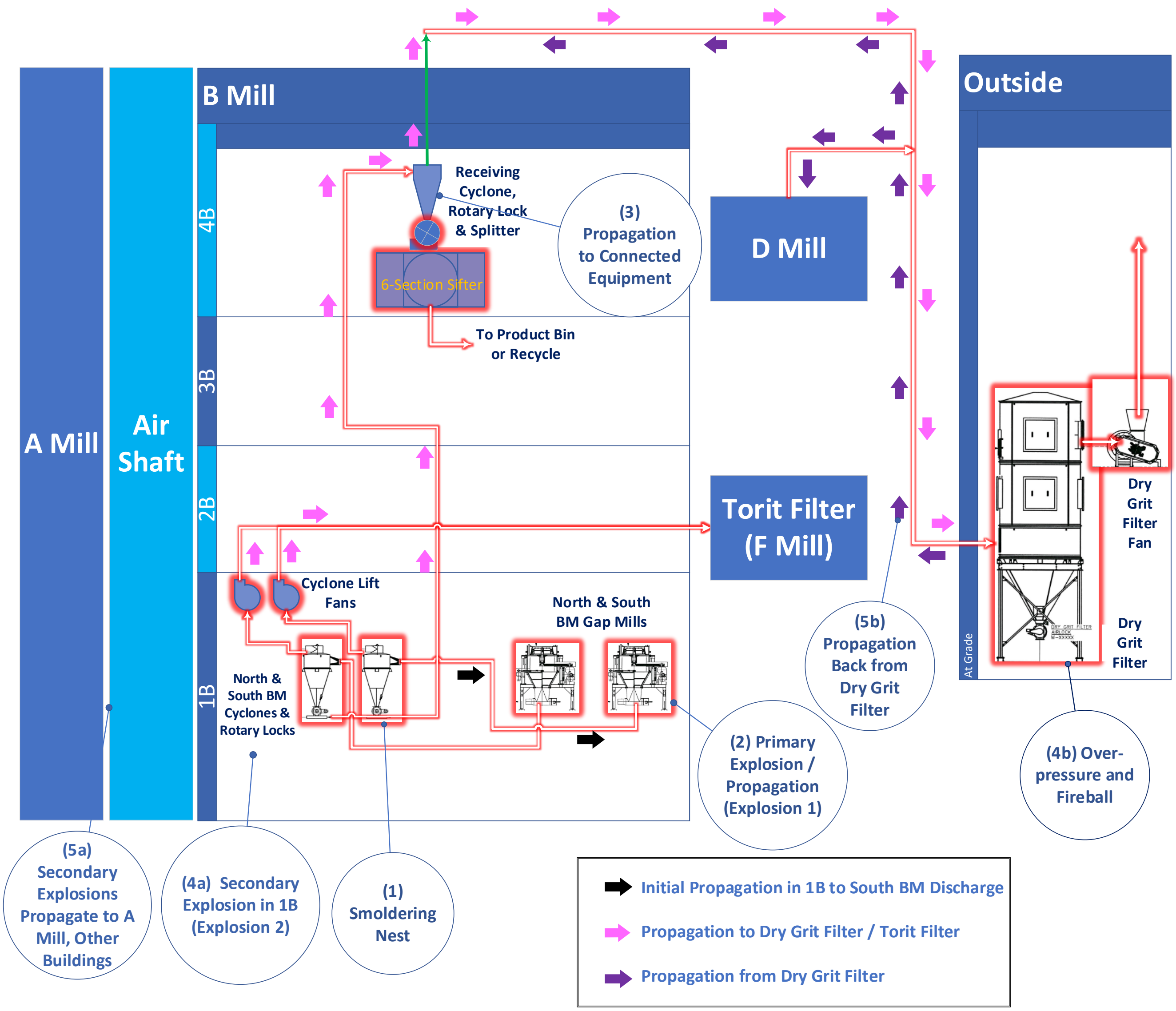

Figure 24: Summary of sequence of events during Didion incident, numbered in order. (Credit: CSB)

3.1.1 Smoldering Nest

A smoldering nest is “[a] small smoldering region within either a dust layer or a much larger quantity of particulate material [12, p. 779].” The smoldering nest can simply be a lump of material that accumulates inside process equipment or adheres to a surface inside the process [40, p. 287]. Burning embers and lumps of material are common ignition sources in dust explosions. Smoldering or flaming particulate embers and smoldering nests can be produced by frictional heating, such as from milling equipment [41, p. 34].

As discussed above in **Section 1.2**, smoldering fires can rapidly transition to a flash fire or explosion if smoldering material is disturbed [10, p. 183]. For organic fuels such as corn, smoldering produces smoke and combustion products such as carbon monoxide, which is itself a flammable gas under certain conditions and can contribute to subsequent fires and explosions. Agricultural grain dusts, among other things, have demonstrated the ability to sustain smoldering combustion [10, p. 183]. Didion had a history of smoldering material inside its processes, particularly when discharge lines plugged on milling equipment, as described below in **Section 4.7.**

For roughly 15 to 25 minutes before the incident began, multiple employees searched for a source of smoke in and near 1B but were unable to locate it. There was no clear smoke source identified and no visible flames observed until after the air intake filter blew off downstream of the South BM. At least five employees searched inside the mill buildings but outside the process equipment for the cause of the smoke that they were seeing and smelling. Several employees mentioned that the smoke was too thin to pinpoint a source. As discussed below in **Section 4.3**, Didion did not use pre-deflagration detection systems that could have detected a smoldering nest or smoke.

The lingering smoke in 1B for roughly 30 minutes prior to the first explosion suggests that a smoldering nest existed somewhere inside the process. A smoldering nest inside the process could provide limited visual cues as employees searched for a smoke source. Smoke from smoldering material inside the Bran process could only escape the process and enter the 1B room through small gaps in ductwork, piping, or equipment, making the source of the smoke more difficult to locate, particularly if it was in the negative pressure pneumatic transport piping and cyclone downstream of the South BM (**Section 2.2.2.2**), as smoke would be more likely to stay inside the process equipment. No employees shut down the Bran process or performed any further investigation to determine where material inside the process was smoldering before the incident occurred, which could explain why they were unsuccessful at finding a source for the smoke. While employees suspected that material was smoldering inside the process, based on feeling the equipment for hot spots or visually checking the South BM Cyclone sight glass, for example, the search was external to the process equipment only, which was common practice at Didion before the incident.

Even if employees had checked for a smolder inside the process equipment, they may not have been aware of a recent temporary change to the Bran process connections that tied the discharge of the North BM and South BM Cyclones together into one product line exiting the bottom of the cyclones. Consequently, employees may have been unaware of some of the equipment that could have been involved and did not realize the full scope of equipment they should check, even if only externally. For example, Employee A mentioned checking for plugging in the South BM Cyclone sight glass but did not mention checking both cyclones. A smoldering nest could have been in a location that the employees did not know to check. Additionally, knowing that the two cyclones were tied together could have alerted employees to an increased possibility that material could have backed up in one of the cyclones, which might have focused their search inside the process more quickly, in time to prevent the incident.

3.1.1.1 Process Data Trends

In the minutes prior to the first explosion, process trends indicated several changes consistent with a smoldering nest and process restriction downstream of the South BM.

First, motor current draw increased throughout the Bran process equipment at approximately 10:12 p.m., likely indicative of a throughput increase, since it occurred in multiple pieces of equipment and somewhat gradually. This in and of itself would not be cause for alarm, since throughput increases are a normal part of operation and milling more corn per hour will require more energy [35, pp. 176-177]. However, higher solids throughput without simultaneously increasing pneumatic transport airflow increases solids concentration and therefore increases the risk of a line restriction or a smoldering nest developing, as more particles are transported with the same amount of transport air through the same size pipe as before. In addition, milling operations in general create significant frictional heat in normal operation; [35, pp. 175-176] so the heat source for smoldering to begin is always available. All that is required is for material to accumulate in an area where that frictional heat cannot dissipate, such as at the top of a cyclone or at a branch or material adhesion in a pneumatic conveying system. Eventually, the smolder can erupt into a deflagration and cause flame propagation without warning, as described in **Section 1.2** [10, p. 183].

From 10:12 p.m. until 10:52 p.m., eight minutes before the explosion occurred at 11:00 p.m., the South BM temperature gradually increased. At approximately 10:52 p.m., the South BM temperature spiked, and the current draw for the transport blower (to 4B) and South BM Cyclone Lift Fan spiked at nearly the same time, as shown in **Figure 25** (center trend). These spikes are consistent with a hot slug of material traveling through the process, briefly plugging the South BM Cyclone Lift Fan and Transport Blower discharge line and clearing out when the spike returned to previous values.

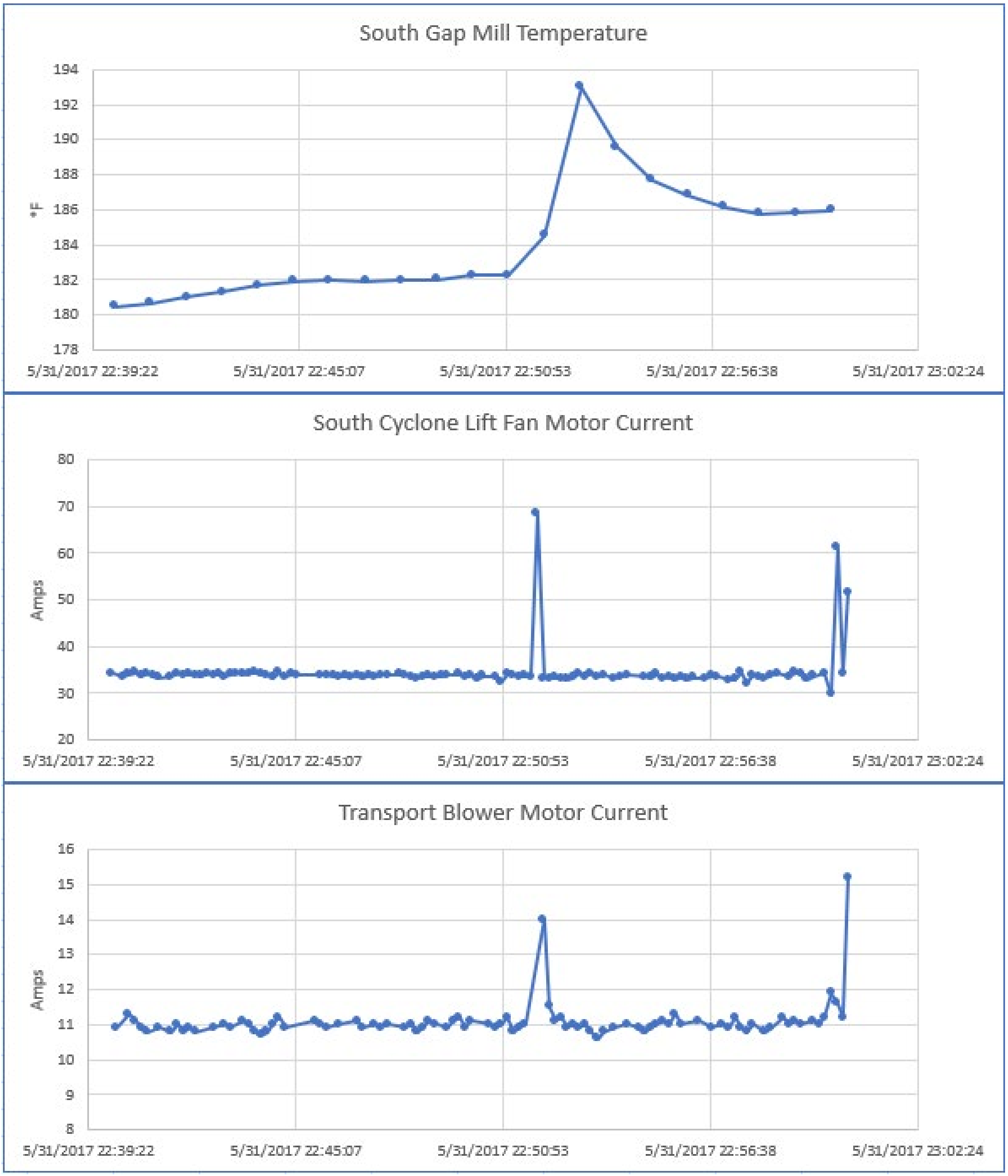

Figure 25: South BM temperature, cyclone fan amps, and transport blower amps in the 20 minutes leading up to the explosion. (Credit: Didion, adapted by CSB)

It should be noted that the temperature indicators for the South BM are near the top of the unit, and hot material below or downstream of the South BM may not be fully detected by temperature sensors near the top of the South BM. Thus, the actual temperatures inside the downstream process could have been higher than indicated inside the South BM.

While not definitive, the process trend data are at least supportive of a transfer line or equipment such as the South BM Cyclone, for example, harboring a smoldering nest, and a slug of hot solid material moving through the process downstream of the South BM approximately eight minutes before the explosion.

The CSB concludes that, although the precise location could not be determined, a smoldering nest likely developed in equipment downstream of the Bauermeister gap mills in 1B, and likely initiated the incident.

3.1.2 Primary Explosion and Initial Propagation

While the employees were searching for a source of smoke on 1B, they heard a “huge boom,” and saw the air intake filter blow off the South BM transfer line to the South Cyclone. Employee A and Employee B noted corn dust material and flames coming out of the air intake for the transfer line out of the South BM as shown in **Figure 17**. As discussed in **Section 2.3.2**, Employee B noted that the flame was visible for several seconds, was “sucked back in,” and then reappeared. This is consistent with and indicative of an oscillating flame and propagation through a pipe, or a series of smaller explosions inside the process, likely originating in the piping or equipment downstream of the South BM.

Previous research by Rae (1973) has noted this type of oscillating flame front behavior during a coal dust propagation experiment in an open-ended gallery, when started by a weak ignition source (such as a smoldering nest) and sustained by coal dust sitting in the bottom of the gallery initially [42, p. 1228]. Starting with a “weak” initiation on the order of 2 pounds force per square inch gauge (psig), flame fronts oscillated in phase with the natural period of the gallery’s air column. The flames appeared at the gallery’s open end at times grouped around multiples of four seconds in Rae’s experiment [42, p. 1228].

A later series of experiments by Eckhoff et al. (1987) in a 22-meter-tall silo yielded a similar result: oscillating pressure and flames were observed, relating them to acoustic waves. “Packets” of flames were ejected at a frequency exactly matching the pressure trace [5, pp. 321-324].

This behavior fits the observed oscillating flames emanating from the open-ended pipe at the air intake line near the South BM discharge, the single “huge boom” eyewitnesses described while still in 1B, and a weak initiation such as a smoldering nest. It was noted in the coal gallery experiments by Rae above that these types of explosions, “although they are included in the general category ‘weak’ in their early stages, […] may nevertheless develop considerable violence later… [42, p. 1226].” Though the “weak initiation” in Rae’s coal gallery experiments started at approximately 2 psig, it developed pressures on the order of 100 psig, demonstrating that combustible dust flame propagations can be highly destructive.

Alternatively, South BM Cyclone Lift Fan could have continued to pull air into the process, if it was still operating, creating a series of deflagrations. Each deflagration would have consumed the air inside the process, and stopped and restarted as the air inside the process was consumed and then replenished by the fan. However, this would have resulted in multiple bangs as successive deflagrations occurred, which was not reported by the eyewitnesses. All other evidence, including the process trends, damage found post-incident, and eyewitness observations, are consistent with either deflagration mechanism.

In the last 30 seconds before the process data historian lost power, the South BM Cyclone Lift Fan motor current oscillated significantly. This was a departure from its behavior at any other time (center trend in **Figure 25** above), and could be explained by either an oscillating flame or a series of deflagrations in or near the South BM Cyclone [5, p. 324].

The CSB concludes that either an oscillating flame front or a series of small explosions spread burning material throughout the Bran process piping on 1B and accelerated a localized smoldering nest into a deflagration.

There is clear photographic evidence of fire damage, and in some cases overpressure, inside the transfer lines connecting both North and South BMs to both receiving cyclones on 1B, the cyclones themselves, both lift fans on 1B, and some downstream equipment from the BM Cyclones on 4B, consistent with a propagating flame through this portion of the process. **Figure 26** shows an overview of this portion of the Bran process with the equipment that indicated at least partial damage from internal fire or deflagration highlighted red.

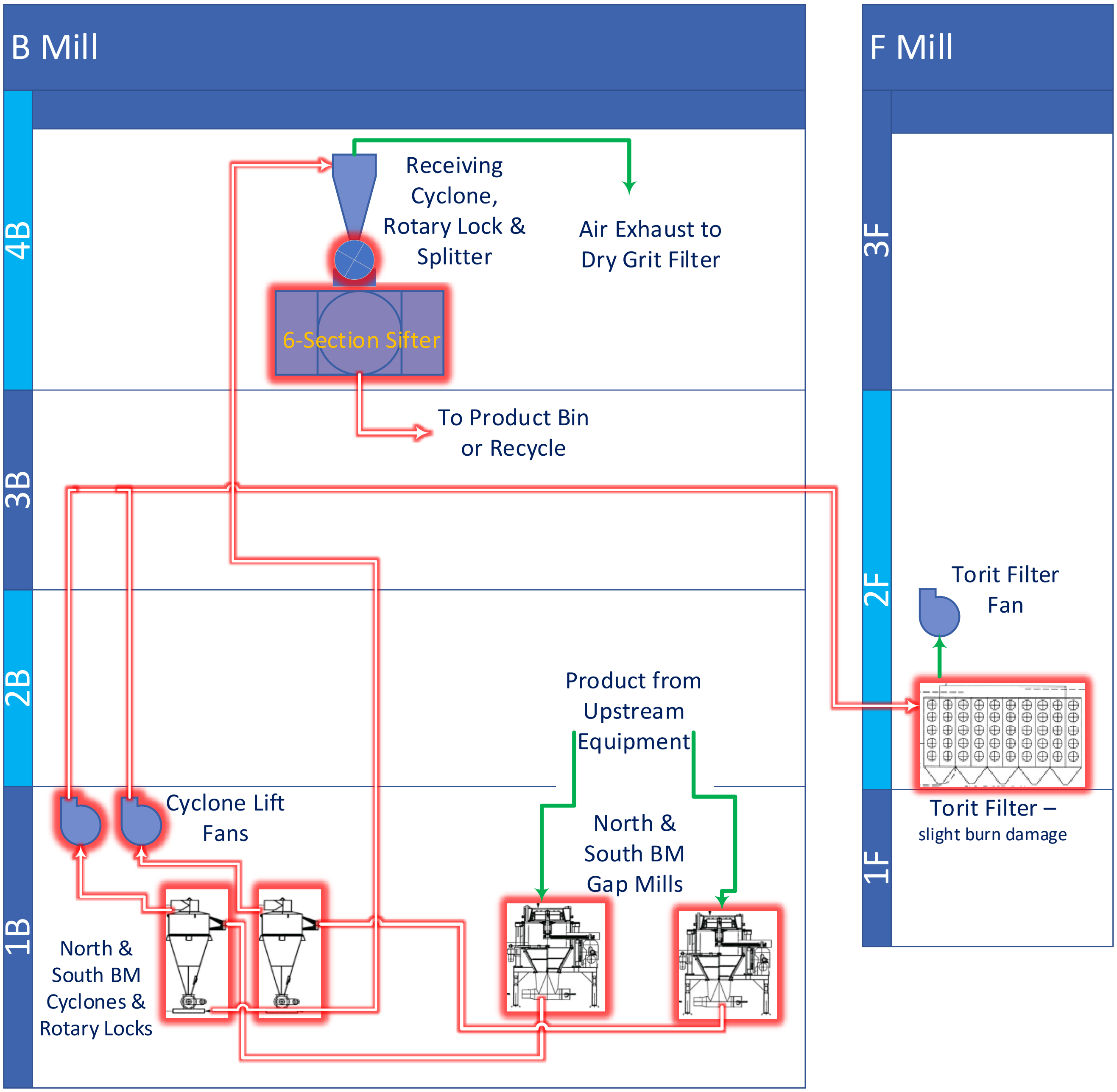

Figure 26: B Mill Bran process equipment with evidence of internal fire damage (highlighted red). Note that not all equipment was internally inspected due to accessibility. (Credit: CSB)

Due to the unstable nature of the site after the incident, the CSB was not able to internally examine equipment downstream of the Bran system equipment on 1B, such as the receiving cyclone or the Six-Section Sifter on 4B. However, some Bran system equipment photographic evidence was available, particularly for equipment on 1B. **Figure 27** shows the South BM Cyclone, separated from overpressure at the top flange. **Figure 28** shows burn damage inside the North and South BM Cyclones. **Figure 29** shows burn damage on the top of the South BM Cyclone.

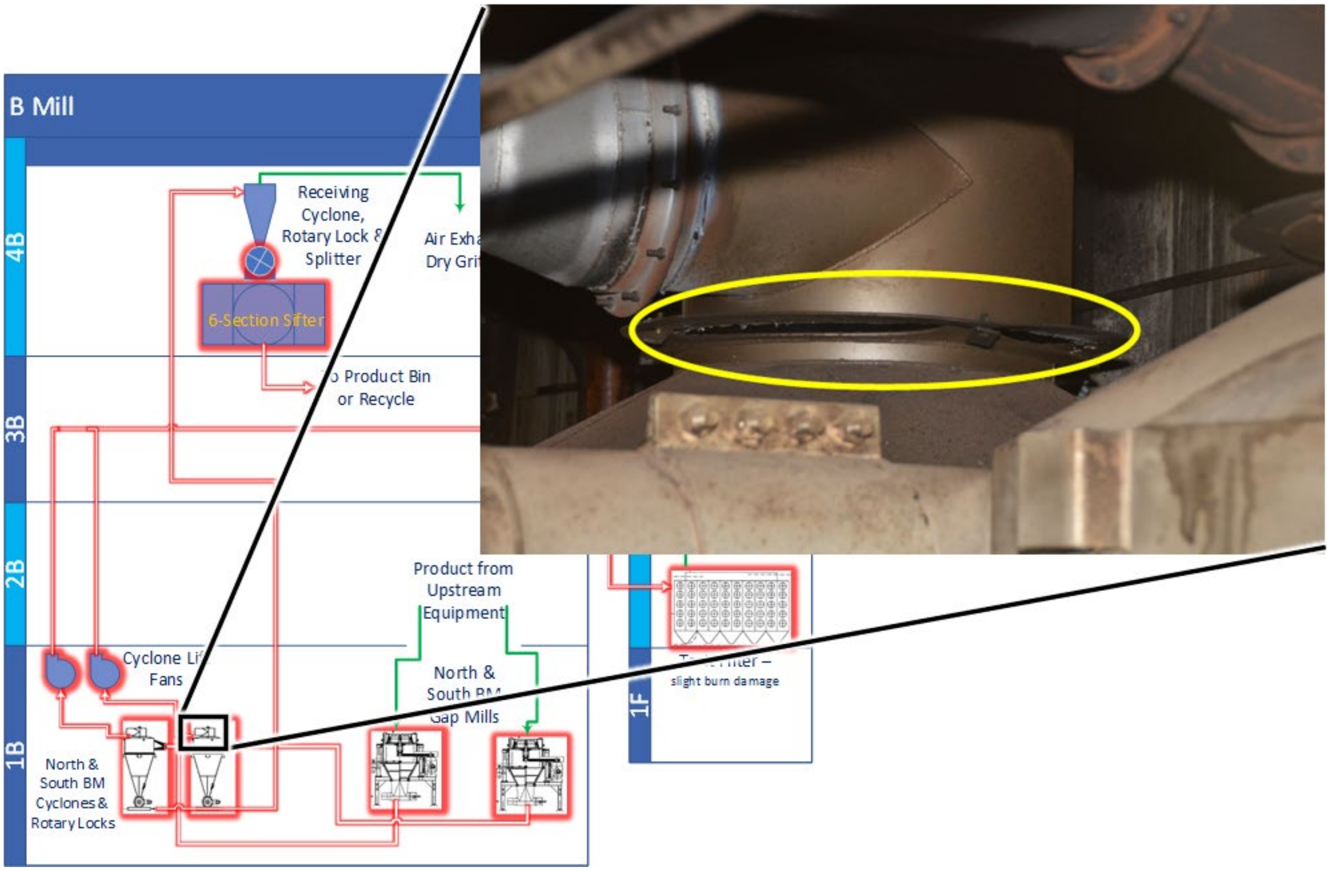

Figure 27: Top (discharge) section of South BM receiving cyclone, separated from body at flange (circled) from an overpressure inside the equipment. (Credit: Didion inset; CSB background)

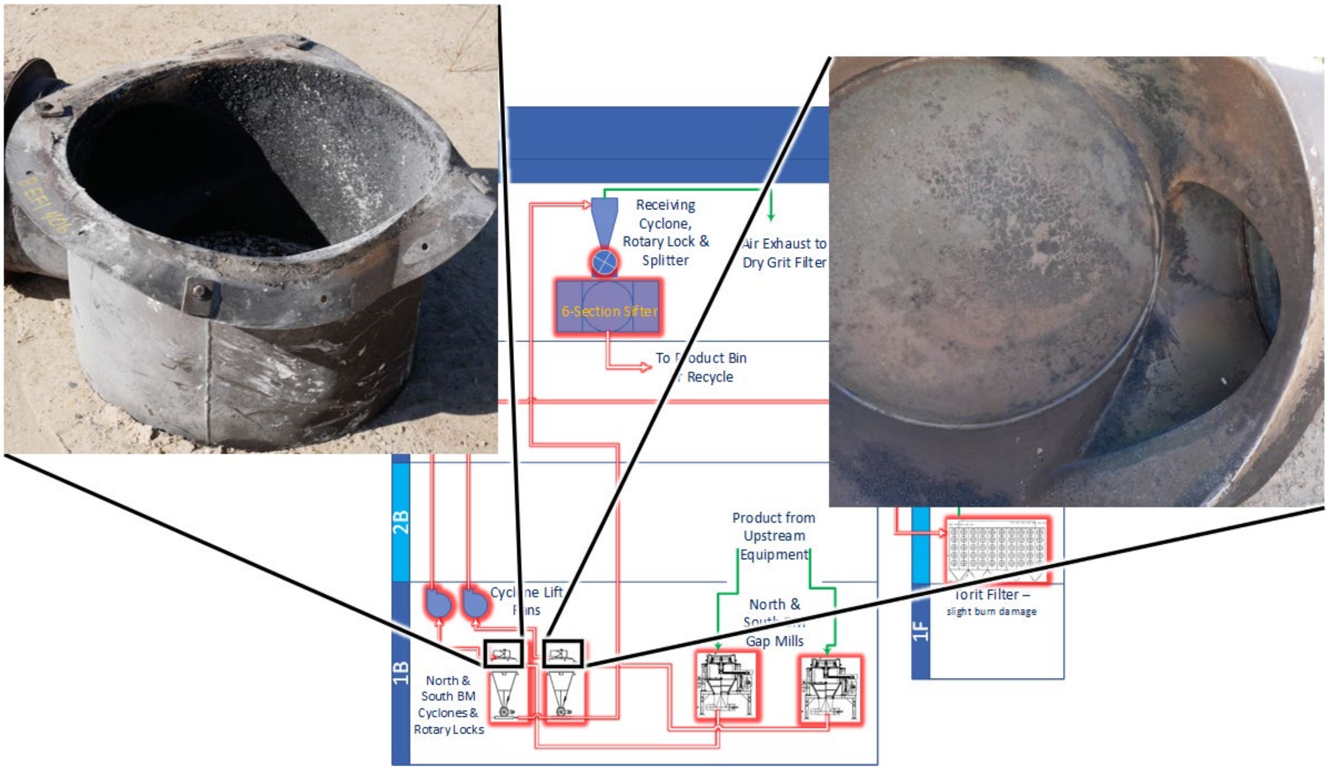

Figure 28: Burn damage inside top of North (left) and South (right) BM Cyclones. (Credit: CSB)

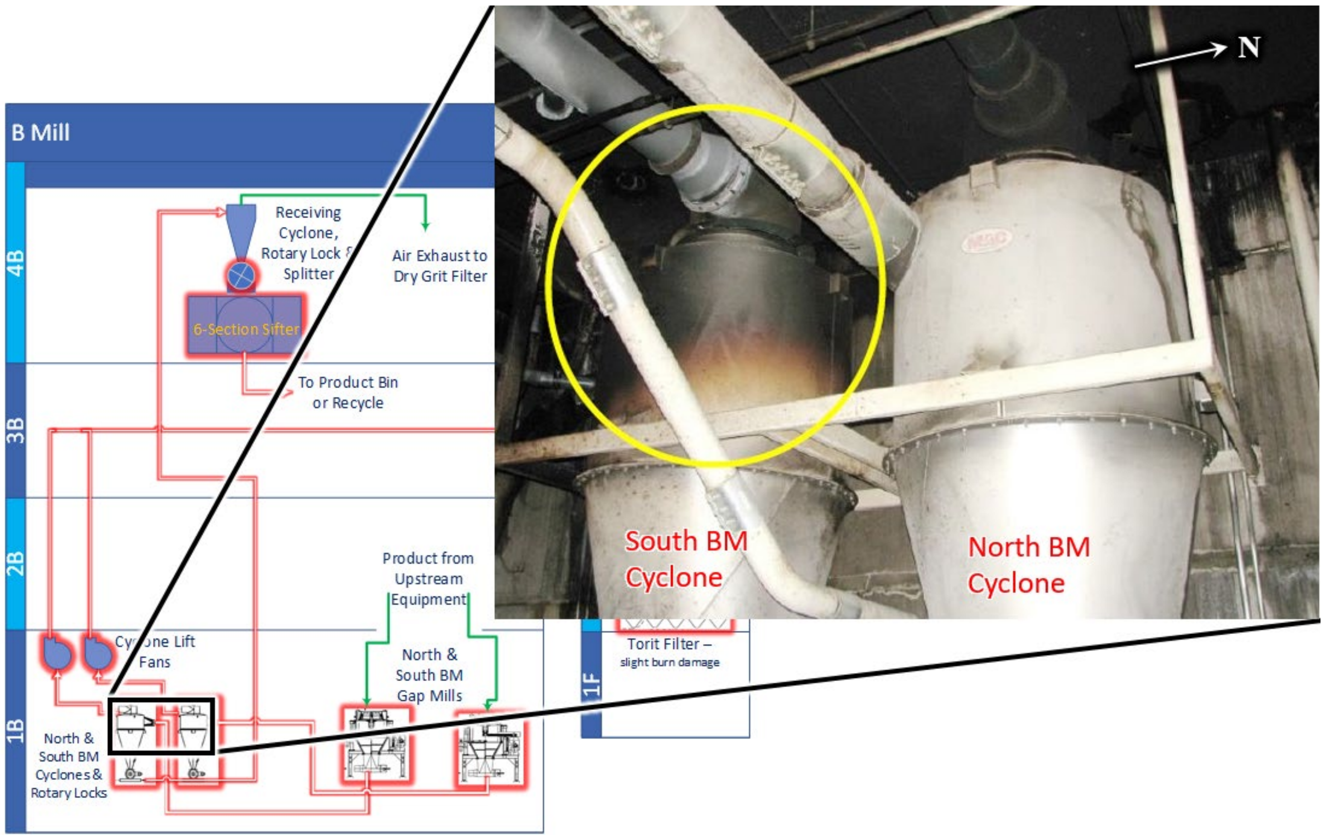

Figure 29: Some of North (right) and South (left) BM Cyclones' burn damage in 1B, circled. (Credit: Didion inset; CSB background and annotations)

Flame propagation through rotary airlocks is a known phenomenon in combustible dust applications where the rotary airlocks are not specifically maintained to prevent propagation [5, pp. 346-351].[a] Rotary airlocks can prevent a combustible dust flame front propagation through them but must be specially designed and maintained with a designated maximum clearance to do so. In this case, the rotary airlocks beneath the North and South BM Cyclones were not designed or maintained as propagation isolation devices, as discussed in **Section 4.3**. Thus, it was possible for a flame front to propagate through the rotary airlocks from 1B to 4B equipment, or vice versa, and ultimately to the Dry Grit Filter. **Figure 30** illustrates burn damage that likely propagated upward through the rotary airlock into the North BM Cyclone, as an example.

[a] *See* Exhibit 0413, at pp. 346-351.

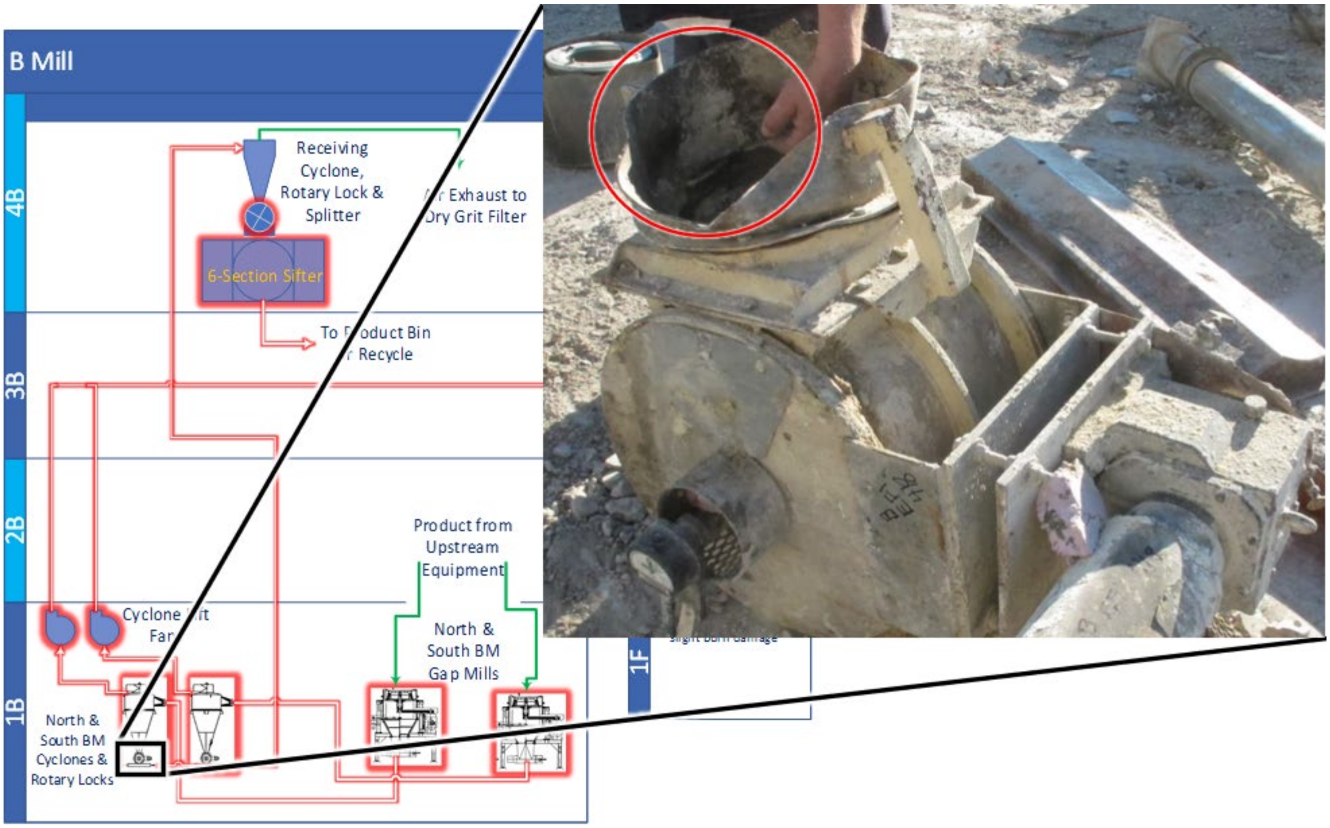

Figure 30: Bottom of North BM receiving cyclone and airlock below, during demolition. The burn mark (circled) is consistent with propagation through airlock. (Credit: Didion inset; CSB background and annotations)

The teardown inspection of the North and South BMs commissioned by the CSB (**Section 2.6.1**) indicated that the material inside the South BM was more charred than in the North BM (**Figure 22** and **Figure 23** in **Section 2.6.1**). There was no evidence of accumulated material or witness marks[a] inside the lower housings of either gap mill, indicating that no accumulated materials burned there. The inspection concluded:

> … there is a potential that the fire ignited downstream of the gap mill…and then travelled as a dust fire/explosion back up through the conveyor duct, which contained a well-dispersed mixture of dust and air.

While it was possible that product ignited upstream of the South BM and was fed to it, the CSB found no evidence for this scenario. All evidence of burned product found inside the process was downstream of the North and South BMs, and the cyclone and piping directly upstream of the South BM did not exhibit signs of fire or explosion damage. Finally, as shown in **Figure 22** and **Figure 23** in **Section 2.6.1**, the bottoms of both the North BM and South BM exhibited the most burn damage, which gradually decreased higher up in the machines.

On the night of the incident, the North BM and South BM Cyclones on 1B both fed to a cyclone on the west side of 4B, just above the Six-Section Sifter. This cyclone's condition was difficult to assess from exterior photos

[a] A witness mark is "a surface mark revealing or confirming some action or process" [88, p. 1033]. In this context, it refers to localized burn marks (or the lack thereof) indicating fire sustained inside the gap mills.

alone, but the Six-Section Sifter just underneath it was burned. The 4B equipment was not available for internal inspection due to structural damage or demolition.

In summary, while not all equipment and piping downstream of the Bauermeister gap mills was available for internal inspection,[a] there was clear evidence of fire and explosions that propagated through the parts of this process.

The CSB concludes that an explosion downstream of the South Gap Mill in 1B occurred, which propagated through the North and South BM Cyclones and continued to propagate throughout the connected process.

3.1.3 Dry Grit Filter Explosion

As noted in **Section 2.3.3**, after the initial explosion and flame at the South BM transfer line, Employees A and B each heard several subsequent explosions as they escaped the mill buildings. One of these explosions occurred when Employee B was escaping from the B Mill building and was running past the Dry Grit Filter.

The Dry Grit Filter and associated equipment showed signs of severe internal damage. The filter socks inside the Dry Grit Filter burned away. The deflagration vents were blown open (**Figure 31**) and in some cases warped such that they could not fully reclose. The Dry Grit Filter blower and its ductwork indicated that there had been an internal combustion or explosion event, or both (**Figure 32**), as evidenced by a rupture in the blower inlet duct, and heat damage and blackened material in several locations. The Dry Grit Filter ductwork was burned and severely damaged.

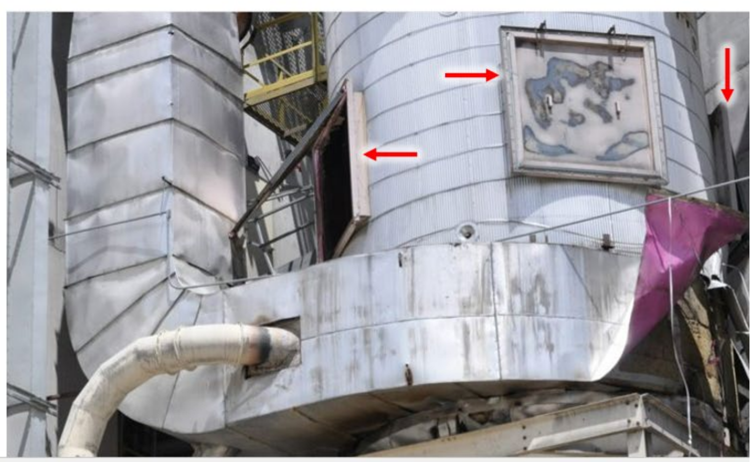

Figure 31: Dry Grit Filter damage. Internal damage (left). The filter socks were burned away, leaving only the metal cages. Deflagration vents (right, red arrows) stuck open and with burn damage. (Credit: Didion, annotations by CSB)

[a] Due to the unstable nature of the site after the incident, not all equipment and locations were available for inspection.

Figure 32: Examples of Dry Grit Filter ductwork and blower damage (red arrows). Inlet duct blackened (shown during demolition, left) and exhaust to atmosphere, including blower (right). (Credit: left, Didion with annotations by CSB; right, CSB)

While there were several potential paths for a deflagration to propagate from 1B to the Dry Grit Filter, the CSB did not have enough evidence to identify a single path with certainty due to the extensive fire and structural damage and the number of process connections to the Dry Grit Filter. Regardless of *how* a deflagration reached the Dry Grit Filter, there is no doubt that it did. In addition to Employee B being knocked to the ground by the Dry Grit Filter explosion during his escape, there was substantial physical evidence of a deflagration as well.

The CSB concludes that the deflagration that began in 1B propagated to the Dry Grit Filter.

3.1.4 Propagation from Dry Grit Filter

Once a propagation reached the Dry Grit Filter, the flame front could continue and propagate to other connected equipment in the mill buildings. Smoldering material inside the ductwork could remain dispersed, or be dispersed again, to continue fueling the propagation.

As noted in **Section 2.2.3.2**, the Dry Grit Filter connected numerous pieces of equipment throughout B Mill, D Mill, one of the packaging areas, and C Mill. Some of the connected equipment and ductwork had internal fire damage in addition to the fire damage inside the Dry Grit Filter itself shown above in **Figure 31**, as well as its ductwork on the roof of B Mill and D Mill.

For example, inside the Grit Dryer system equipment in D Mill, which is one of the processes directly connected to the Dry Grit Filter by ductwork, there was evidence of fire internal to the Grit Dryer system, despite minimal fire damage inside the D Mill building at large. **Figure 33** shows an overview of the Grit Dryer system damage, highlighted red. Some equipment inside D Mill could not be fully inspected due to structural damage and demolition, so additional burn damage may have occurred that was not observed due to equipment inaccessibility.

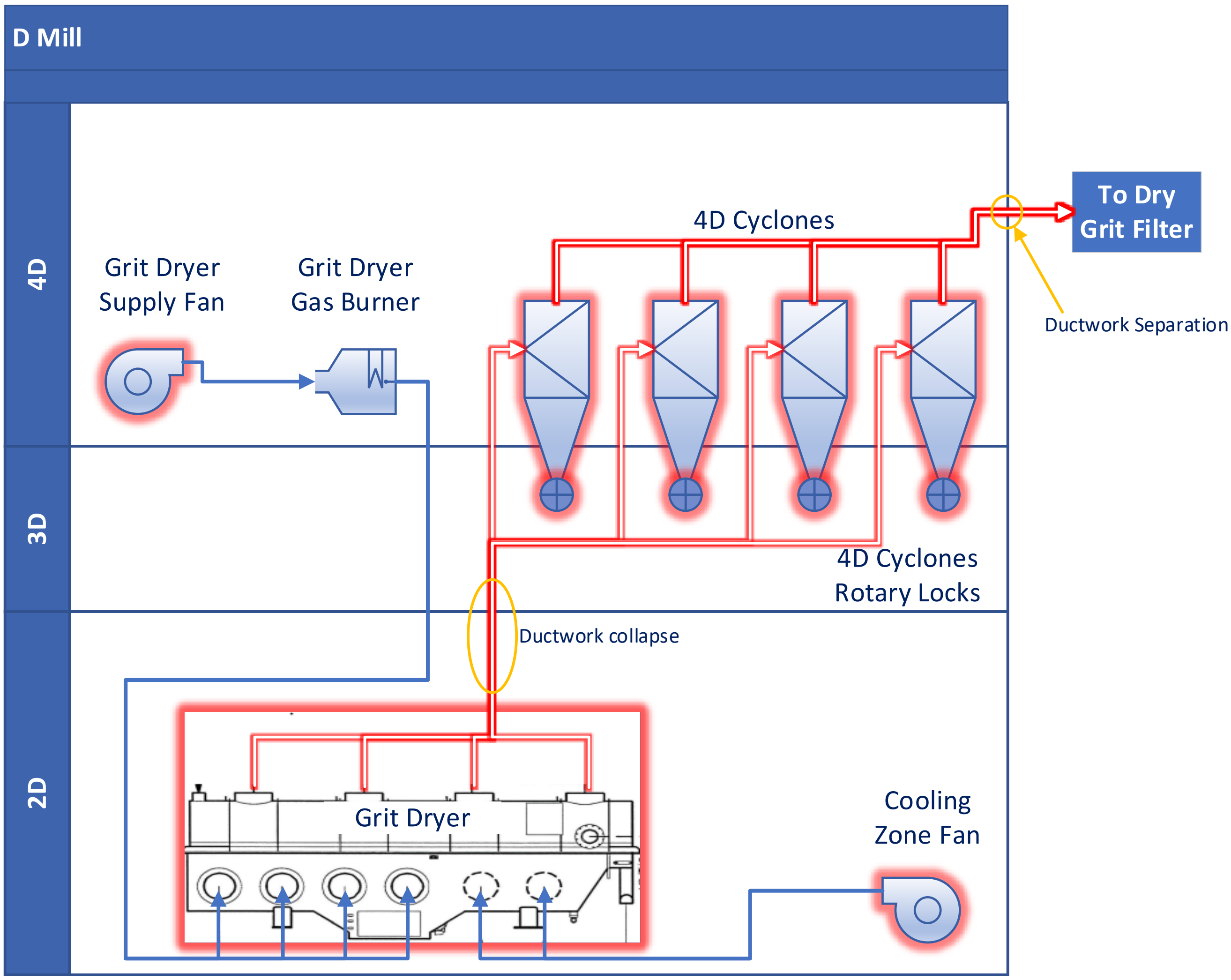

Figure 33: Summary of burn damage found inside the Grit Dryer system, highlighted red, and connection to Dry Grit Filter. Note that some equipment was inaccessible and not inspected internally. (Credit: CSB)

The Grit Dryer system was not directly connected to the Bran process on 1B where the first explosion occurred. The only connection between the two processes was through the Dry Grit Filter. **Figure 33** shows one likely path from the initial explosion on 1B, to the Dry Grit Filter, and then back out to the Grit Dryer system. As discussed above, there were several potential paths from 1B to the Dry Grit Filter, but the path from Dry Grit Filter to Grit Dryer system is clear, as shown in **Figure 34**. **Figure 35** shows an example of fire damage to the Grit Dryer exhaust ductwork that led to the Dry Grit Filter.

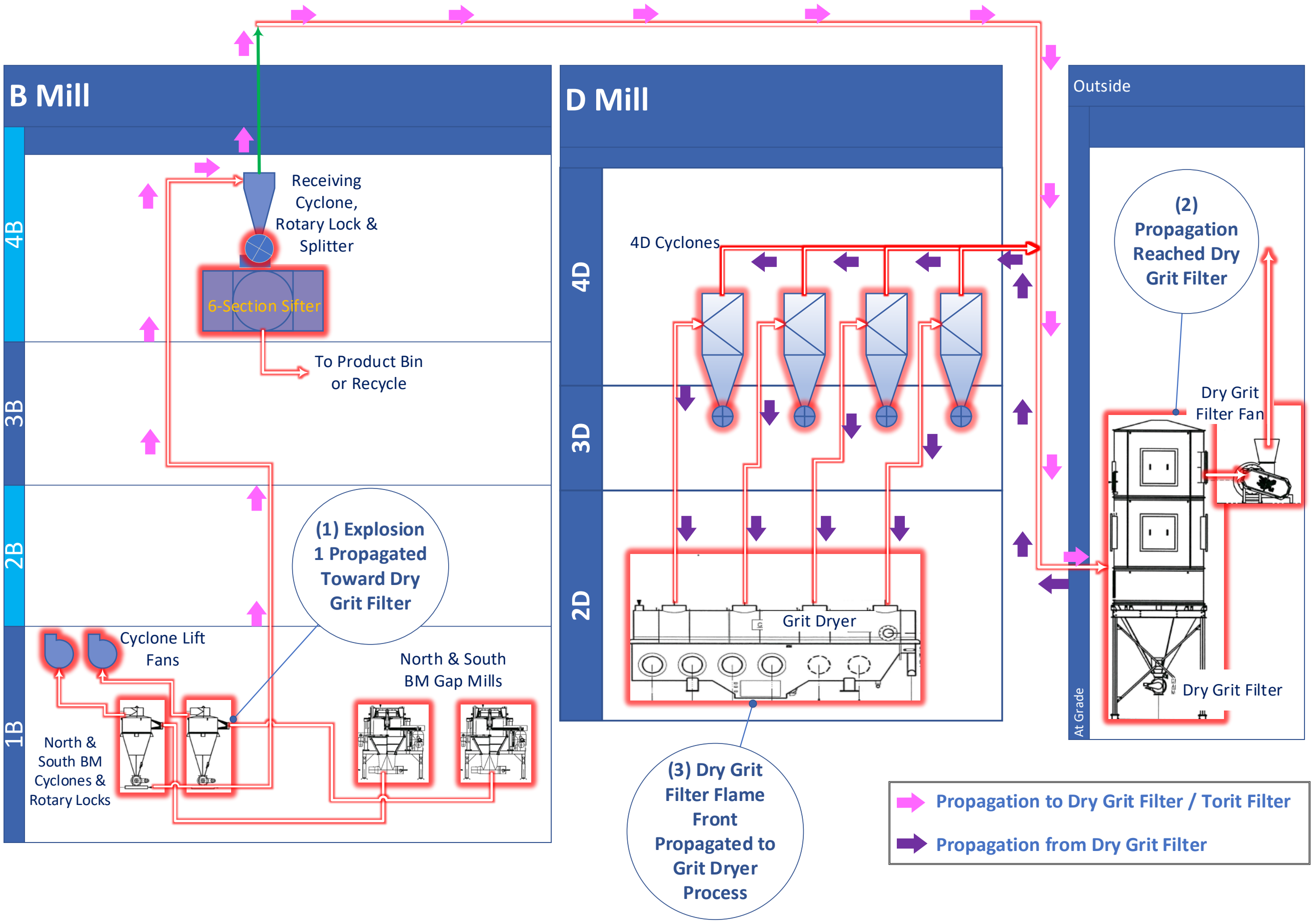

Figure 34: Potential path for propagation from 1B to Dry Grit Filter (pink arrows) to (simplified) Grit Dryer system (purple arrows). Known internal fire damage is highlighted red. (Credit: CSB)

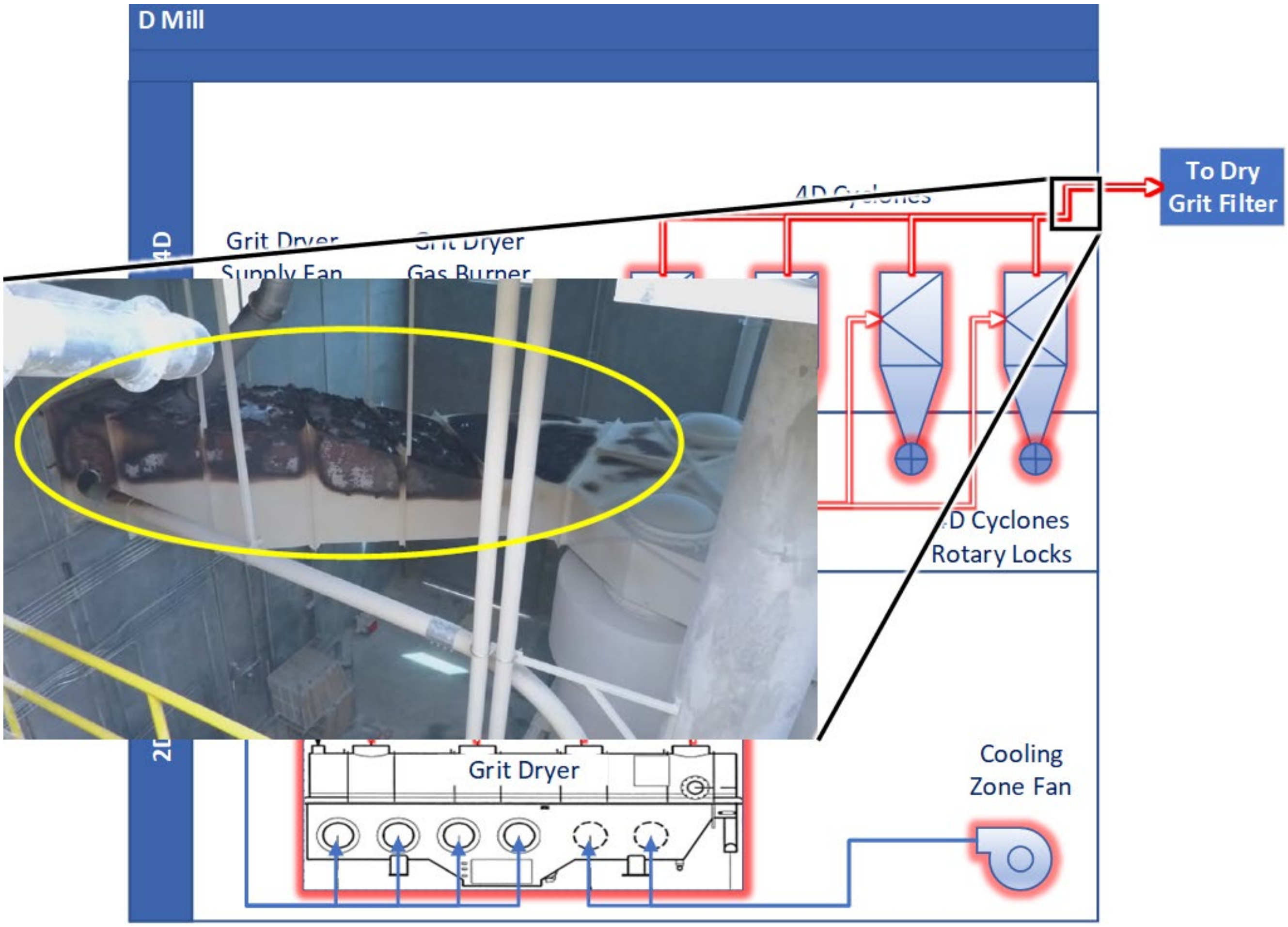

Figure 35: Grit Dryer exhaust ductwork damage, circled. The Dry Grit Filter is just outside the wall. (Credit: inset, Didion; background, CSB)

The Grit Dryer's burner fan and cooling zone fan, both of which supplied fresh air to the dryer, showed black burn marks coming out of each fan's suction. **Figure 36** shows the burn marks inside the Grit Dryer burner supply fan intake, which under normal circumstances would intake outside fresh air.

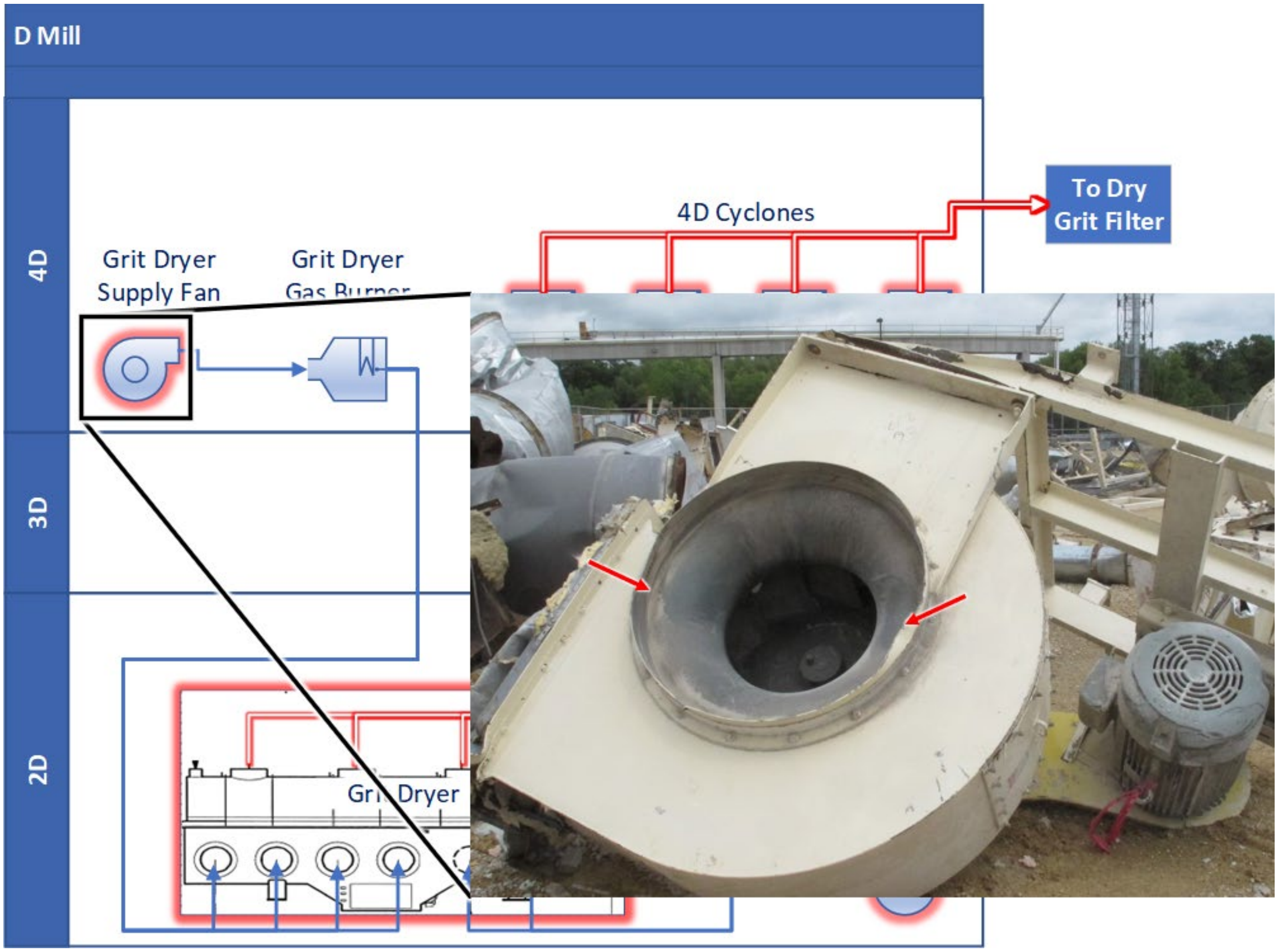

Figure 36: Grit Dryer burner supply fan, post-demolition. Note burn marks on fan suction and inside (arrows). (Credit: inset, Didion with annotations by CSB; background, CSB)

As a pressure wave propagates through a pipeline (**Section 1.2**), a negative pressure relative to atmospheric pressure is commonly observed following the pressure wave. The air ahead of the flame front is accelerated by combustion products. This leaves a lower pressure, sometimes negative pressure relative to atmospheric, behind the flame front [10, p. 519]. **Figure 37** shows the pressure profile of such a pressure wave at a fixed point in a duct, downstream of an ignition. Since the pressure goes below atmospheric following the flame front in many cases, collapsed ductwork following a deflagration pressure wave is not uncommon. This was observed in the Grit Dryer exhaust ductwork after the incident, as shown in **Figure 38**.

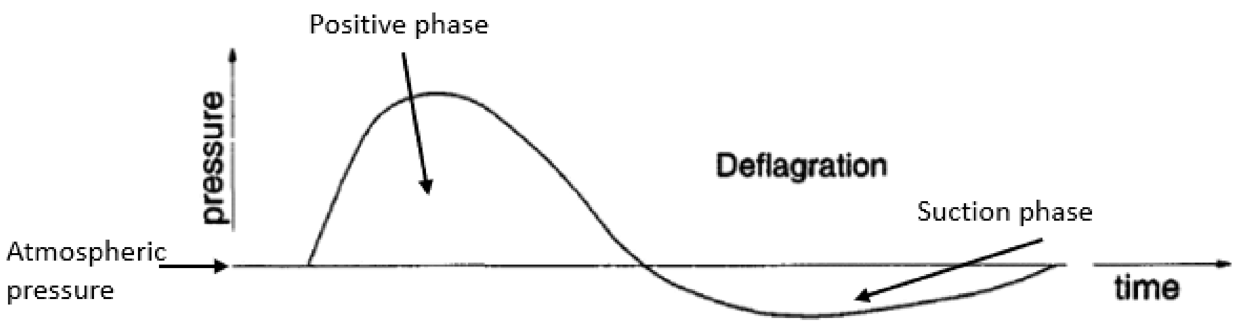

Figure 37: Pressure wave features as the wave propagates through a pipe at a fixed point in the pipe. Note that pressure goes below atmospheric behind the pressure wave (suction phase). (Credit: CCPS; Ogle; annotations by CSB) [43, p. 133] [10, p. 519]

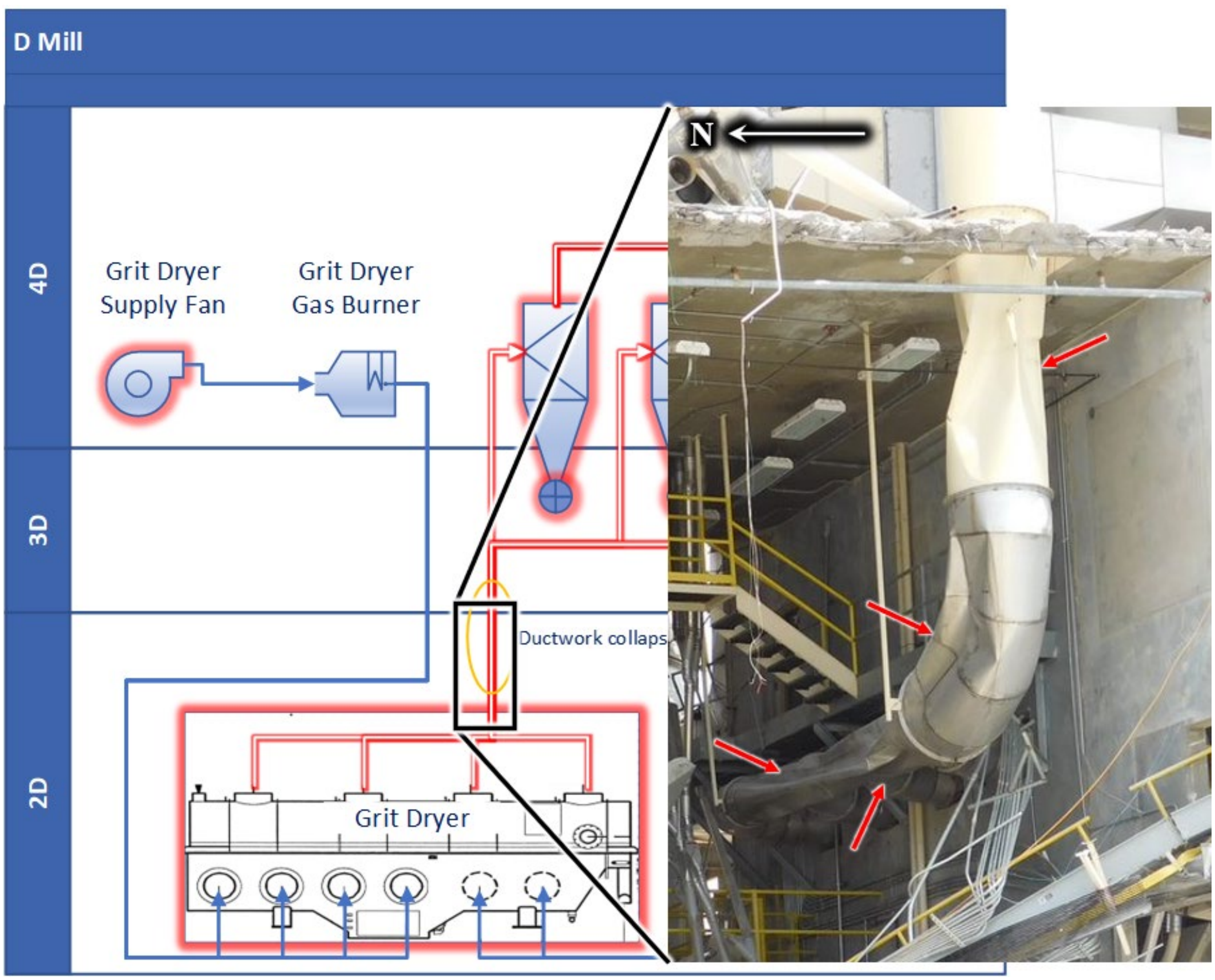

Figure 38: Grit Dryer exhaust ductwork in D Mill, between Grit Dryer and 4D cyclones, found collapsed post-incident (red arrows). (Credit: Didion, annotations by CSB)

The CSB concludes that a deflagration in the Dry Grit Filter propagated to other previously uninvolved parts of Didion's processes, which allowed explosions and fire to continue to spread throughout the mill processes.

Although connected to the North and South BM processes, the Torit Filter itself contained mostly unburned corn dust. The Torit Filter was located in 3F, directly connected to the process downstream of both North and South Cyclone Fans in 1B. The ductwork leading to the Torit Filter did show signs of overpressure, where the flanges had begun to pull apart. However, the inside of the Torit Filter itself had very little fire damage. This is likely due to one of two scenarios: either the building collapse occurred, causing the ductwork to lose containment, or the ductwork overpressure itself released enough pressure through the openings created by the overpressure to stop the propagation.[a] **Figure 39** shows the heat damage at the Torit Filter inlet and the minimal damage inside the filter.

Figure 39: Torit Filter damage: inlet baffle heat damage (left), dark residue inside (center), and a filter element removed (right). (Credit: Didion)

3.1.5 Secondary Explosions

A number of secondary dust explosions occurred after the initial explosion in 1B, described above in **Section 3.1.2**, and in parallel with the ensuing deflagrations propagating throughout the process. Some of these were directly witnessed by employees, and others were identified based on physical evidence after the incident.

The secondary explosions likely began near the site of the primary explosion on 1B, where the air intake filter popped off the South BM discharge line. Process material blew out of the filter process piping and lofted into the air. As process material from the primary explosion blew out into 1B, this disturbance also lofted fugitive dust already present in 1B. The two fuel sources created conditions for a secondary dust cloud explosion, as described in **Section 1.2**. Employees A and B witnessed dust falling from the ceiling in 1B, and seeing the flames, they evacuated 1B. Employee A, in the second-floor hallway near the control room, witnessed a fireball coming up the stairwell from 1B. The damage inside and surrounding 1B, explosion directional analysis, and building collapse analysis all support a secondary explosion in 1B (see **Section 3.2** and **Appendices D** and **E**).

[a] Both scenarios involve removing the confinement leg of the dust explosion pentagon.

As pressure, dust, and flames escaped the process equipment throughout the buildings due to deflagrations propagating throughout the process, and more fugitive dust inside the buildings could be lofted, this created a situation likely to trigger cascading flash fires and explosions outside the process and inside the buildings, as described in **Section 1.2**. Process material blown out of the process and fugitive dust already inside the buildings could be lofted by previous explosions, creating the series of subsequent explosions reported by employees and described in **Section 2.3**. Ultimately several buildings collapsed, as described in **Section 2.3.3**. The likely causes were process dust ejected from equipment and ductwork and lofted fugitive dust. Employees reported thick dust in the air both inside 1B and in the hallway near the control room just before significant explosions occurred. This demonstrates that thick dust was observed in the air outside 1B, unrelated to the material ejected from the South BM area.

The CSB concludes that the primary explosion in 1B and the ensuing propagations lofted fugitive dust and spread secondary explosions throughout the mill facility.

In the north end of the facility in A Mill, the CSB found no evidence of dust explosions or deflagration inside the process equipment. Significant evidence of dust explosions and fires outside the process was found, including burned residue and fire damage on the outside of equipment and some structural damage. Explosion directional analysis and building collapse analysis performed for the CSB (see **Appendices D** and **E**) indicate that the air supply shafts between A Mill and B Mill allowed explosions to propagate upward from 1B throughout A Mill and B Mill. The B Mill air shaft structural damage was particularly prominent, with several cracked or broken wall panels, as shown in **Figure 40**.

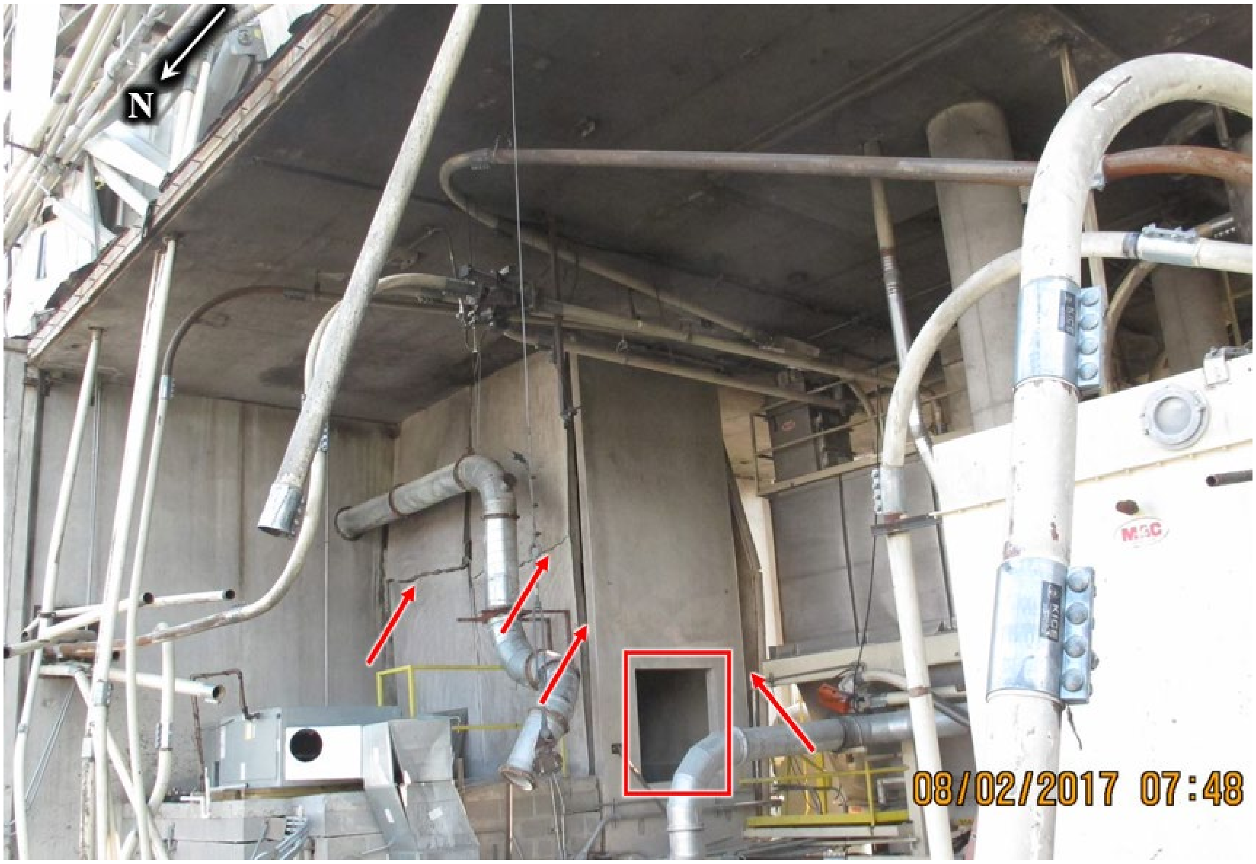

Figure 40: 4B air shaft damage (red arrows) and shaft opening into 4B (red box) in B Mill interior, pre-demolition. The 4B wall panels detached from the B Mill structure during the incident. (Credit: Didion, annotations by CSB)

This air shaft propagation likely caused the significant overpressure and wall damage at 4A as well, as shown in **Figure 41**. Because A Mill construction was much stronger than other mill buildings (see **Appendix D** and **Section 4.4**), a large building overpressure was required to cause this damage. Given the lack of evidence to indicate significant process equipment involvement in A Mill, and the clear damage in the A Mill building structure, including the air shaft, a building explosion in or near 4A that did not involve the process equipment directly would have been necessary to produce the damage observed.

Figure 41: 4A structural damage. Wall bowed and separated from door frame (left, at arrows) and wall separated from floor (right, at orange arrows). Note that wall displacement caused concrete damage, exposing rebar (red arrows). (Credit: CSB)

The CSB concludes that secondary explosions contributed to the incident, and secondary explosions were necessary to produce some of the damage observed after the incident.

3.2 Structural Collapse

After he escaped the mill buildings and while he was trying to call 911, Employee B noted that a fireball he estimated to be more than 100 feet above the ground, near the center of the mill. This was likely an explosion near or in 4B or 4A air shafts, and likely a final propagation upward through the air shafts from lower levels. An explosion in this scenario would explain why the fireball observed was so high above the ground. This would also explain why the 4B wall panels landed on top of the other collapsed buildings, as described below in this section.

A structural analysis commissioned by the CSB (**Appendix D**) determined that the building collapse events occurred in three stages:

1. The initial process explosion in 1B vented into the B Mill airshaft, A Mill, and D Mill's lower stories. B Mill's lower tier wall panels bulged outward, shifting, and destabilizing adjacent structures in C Mill and F Mill.
2. C Mill, parts of the Multipurpose Building, F Mill, and the Boiler Room collapsed.

3. After the collapses, a secondary blast pressurized the 4B interior, blew 4B wall panels off the building, and the 4B wall panels fell on top of the collapse debris.

Because the initial building pressurization was centrally located in 1B, and because of the add-on construction using shared walls, the first explosion on 1B had a destabilizing effect on many mill facility structures almost simultaneously, leaving employees without enough time to escape the collapsing buildings once the initial blast began. **Figure 42** illustrates the destabilizing effect that a 1B blast wave could cause. This structural design is discussed further in **Section 4.4**. The full structural analysis report is in **Appendix D**.

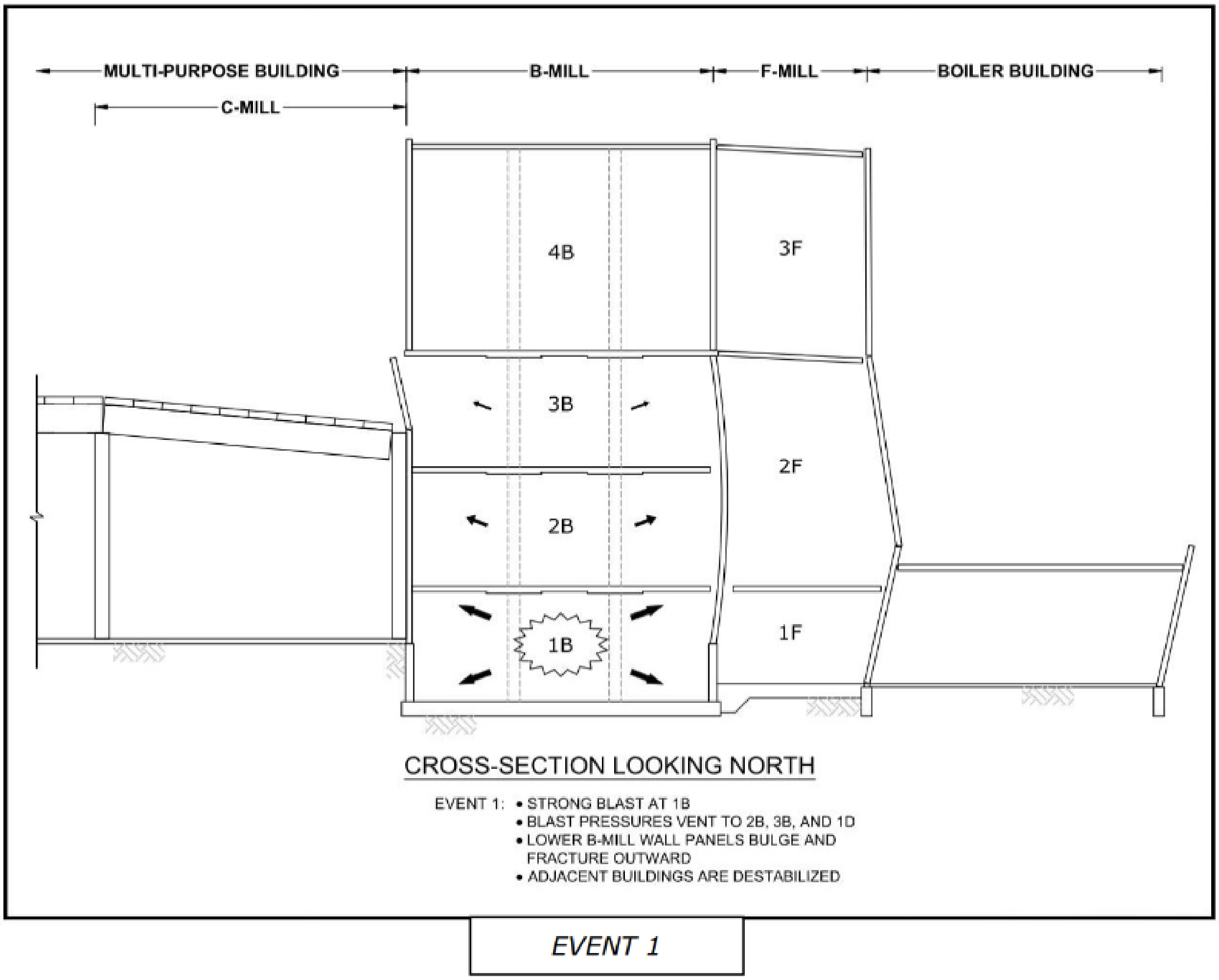

Figure 42: Destabilizing results of an initial blast in 1B. (Credit: CSB)

According to the structural analysis, it took only three to five seconds for connections and structural members to break apart and for the broken pieces to fall to the ground in C Mill, the Multipurpose Building, F Mill, and the Boiler Room. After the incident, the 4B wall panels were found resting on top of F Mill and the Boiler Room rubble on the east side and C Mill and Multipurpose Building rubble on the west side. This indicates that the 4B wall panels likely separated from the building and fell at least several seconds after the other buildings collapsed.

The CSB concludes that a primary explosion inside process equipment located in 1B initiated a secondary explosion inside the building on 1B. The primary explosion inside the equipment propagated through other connected equipment, and the secondary explosion propagated through the connected air supply shafts and other openings to cause fire and structural damage to equipment and buildings in areas not associated with the equipment in 1B. Additionally, the CSB concludes that Didion's add-on building design employing shared walls between connected mill buildings caused multiple buildings to collapse and significant structural damage throughout the mill facility, which caused multiple fatalities and injuries to employees.

4 Safety Issues

The following sections discuss the safety issues contributing to the incident, which include:

- Process Hazard Recognition (**Section 4.1**)
- Dust Hazard Analysis (**Section 4.2**)
- Engineering Controls for Combustible Dust Hazards (**Section 4.3**)
- Structural Design for Combustible Dust Hazards (**Section 4.4**)
- Fugitive Dust Management (**Section 4.5**)
- Management of Change (**Section 4.6**)
- Incident Investigation (**Section 4.7**)
- Process Safety Information (**Section 4.8**)
- Management of External Audits and Inspections (**Section 4.9**)
- Emergency Preparedness (**Section 4.10**)
- Personal Protective Equipment (**Section 4.11**)
- Process Safety Leadership (**Section 4.12**)
- Regulatory Coverage of Combustible Dust (**Section 4.13**)

4.1 Process Hazard Recognition

As described in **Section 2.1**, the mill facility was built over a period of nearly 20 years. New processes were added on, or existing ones modified, many times during this period. Ongoing process modifications occurred throughout the mill facility's history, prompting continual process design and redesign efforts for each process addition or modification.

Didion's process designs lacked several safeguards and did not follow well-known design good practices, which if followed, could have prevented the incident. Deficiencies included:

- Didion did not recognize that many of its products and waste streams were combustible dusts or contained significant amounts of combustible dust. While Didion did recognize some process streams as potentially combustible, other process streams that Didion did not treat as combustible were likely directly involved in the incident.

- Didion did not recognize that interconnecting equipment through dust collectors could present a deflagration propagation hazard and as a result did not mitigate this hazard, which allowed deflagration(s) to propagate throughout the mill facility on the night of the incident.
- Didion incorrectly calculated the combustible dust concentrations in its dust collectors, and incorrectly concluded that dust collectors in the mill facility did not contain explosive dust concentrations, causing Didion to incorrectly conclude that there were no combustible dust hazards to be mitigated in its dust collection systems, which contributed to the incident's severity.
- Didion did not recognize that proper ductwork systems design and verification were crucial for safe dust collector operation and pneumatic conveying, and that failure to design and maintain these systems correctly allowed combustible material to accumulate inside ductwork systems, contributing to the incident's severity.

4.1.1 Identifying Combustible Dust

<u>Didion's Hazard Information</u>

The CSB requested that Didion provide all analytical reports depicting initial characterization test results for combustible dusts. Didion was unable to provide any such testing reports, but did provide dust collector calculations and Safety Data Sheets (SDSs). Among other warnings regarding combustible dust or dust inhalation, the SDSs included the following warning language:

> CAUTION! If small particles are generated during further processing, handling or by other means, product may form combustible dust concentrations when suspended in air. Keep away from sources of ignition, sparks, and open flames. Use only in well-ventilated areas. Provide adequate dust control. (*Hazards Identification – Emergency Overview*)[a]
>
> Dust-air mixtures may be explosive. (*Fire Fighting Measures*)
>
> Prevent electrostatic charge build-up by using common bonding and grounding techniques. Store in a well-ventilated place. Keep container tightly closed. Avoid dust formation. Guard against dust accumulation of this material. Use care in handling/storage. (*Storage*)
>
> Avoid spread of dust. Avoid heat, flames, sparks and other sources of ignition. (*Conditions to Avoid*)
>
> Refer to NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, for safe handling. (*Other Information – Further Information*)

[a] Descriptors in parentheses, e.g. *(Hazards Identification – Emergency Overview),* correspond to SDS section headings where the listed warnings were found.

Didion's SDSs provided dust explosion properties such as maximum explosion pressure (P_{max}), maximum rate of explosion pressure rise (dP/dt_{max}), deflagration index (K_{St}), minimum explosible concentration (MEC), minimum ignition energy (MIE), and minimum ignition temperature (MIT), as shown in **Figure 43** below. This information was included in SDSs for finished products.

Dust explosion properties

Pmax	7.9 bar
dP/dT	397 bar/s
Kst	180 bar·m/s
Minimum explosible concentration (MEC)	120 - 140 g/m3
Minimum Ignition Energy (MIE) - dust cloud	500 - 1000 mJ
Minimum Ignition Temperature (MIT) - dust cloud	770 - 788 °F (410 - 420 °C)

Figure 43: Excerpt of Didion SDS for dust properties. (Credit: Didion, annotations by CSB)

Of particular importance are P_{max}, K_{St}, and MEC due to the nature of the combustible dusts at Didion. Accurate property data are important in designing explosion protection systems, which is further discussed in **Section 4.3**. This is the information necessary for facilities when evaluating inherently safer design strategies and active or passive engineering controls.

The P_{max} indicates the "maximum pressure developed in a contained deflagration of an optimum mixture" [44, p. 8]. The P_{max} provides guidance for equipment design considerations. Inadequately designed equipment can deform or rupture in a dust explosion; "the higher the P_{max} developed by a dust deflagration, the greater the hazard [45, p. 10]." The K_{St} is a value used to describe the severity of the explosion, where "any combustible dust with a K_{St} value greater than zero can be subject to dust deflagration [45, p. 10]." The MEC defines the "minimum concentration of a combustible dust suspended in air, measured in mass per unit volume, that will support a deflagration [6, p. 9]." P_{max}, K_{St}, and MEC can be influenced by several factors, including particle size distribution, moisture content, and other factors [45, p. 9]. In every Didion product SDS, Didion noted an MEC for flammability limits (**Figure 44**).

Flammability limits in air, upper, % by volume **Flammability limits in air, lower, % by volume**	WHEN DISPERSED INTO THE AIR IN SUFFICIENT CONCENTRATIONS GRAIN DUST CAN EXPLODE IN THE PRESENCE OF AN IGNITION SOURCE. DO NOT ALLOW DUST TO BECOME DISPERSED INTO THE AIR, EVEN BY THE EXTINGUISHING AGENT. MINIMUM EXPLOSIVE CONCENTRATION IS *55 G/M3*. HOWEVER, MOISTURE CONTENT, PARTICLE SIZE, CALORIC PROPERTIES, AND SPECIFIC INGREDIENTS ALSO AFFECT THE EXPLOSIVENESS OF GRAIN DUST.

Figure 44: Flammability limits as shown on Didion SDSs. (Credit: Didion)

Although Didion did not provide the source for the data published in its SDSs, a customer reading the SDS should consider Didion's products and intermediates as combustible dust.

Particle Size Data

The current NFPA definitions of combustible dust (**Section 1.2**), or agricultural combustible dust, do not use a defined particle size as a criterion, although according to several NFPA standards, "For consistency with other standards, 500 microns (capable of passing through a U.S. No. 35 Standard Sieve) is now considered an appropriate size criterion [46, p. 26]." [a] The 2020 edition of NFPA 61 also defines "…agricultural combustible dust is material 500 µm or smaller in diameter or 500 µm or smaller in one dimension…" and has additional combustible dust characteristics, such as a K_{St} less than 200 and a MEC greater than 40 g/m^3 [23].

Historically, NFPA standards, including the 2008 edition of NFPA 61, defined combustible dust or agricultural dust as "Any finely divided solid [agricultural] material *420 microns or smaller* in diameter (material passing a U.S. No. 40 Standard Sieve) that presents a fire or explosion hazard when dispersed and ignited in air" (emphasis added) [47, p. 5]. This likely explains Didion's calculations' past references to only particles smaller than 425 or 420 microns, the approximate hole size in a U.S. No. 40 Standard Sieve, as discussed below in **Section 4.1.3**.

After the incident, the CSB collected samples at the incident scene to measure the particle size distribution of various product streams, including product material, in-process material, and material inside dust collectors. For comparison to Didion's product literature, these samples were analyzed for particle size distribution as received at the testing laboratory. **Table 2** below indicates that particle sizes of as-found samples at the incident scene were similar to published Didion specifications, namely that nearly all material tested was below a 425-micron particle size.

[a] The NFPA also notes that particle shape is important, for example in NFPA 61 (2017): "Due to particle shape and agglomeration, some particulates cannot be sieved effectively. Particulates with nonspheric or noncubic shapes do not pass through a sieve as easily as spheric or cubic particles. For this purpose, fibers can behave just as explosively as spherical particulate. This leads to underestimation of small particle populations and to underassessment of the hazard" [6, p. 31].

Table 2: Particle size distributions for several Didion products as reported by Didion, and CSB-collected samples.[a] Numbers highlighted yellow indicate the percentage of sample meeting the historical combustible dust definition of under 425 microns. (Credit: Didion; CSB)

Material	Wt Percent under 425 microns (Didion)[b]	Wt Percent under 150 microns (Didion)	Vol Percent under 425 microns (CSB)	Vol Percent under 150 microns (CSB)	Vol Percent under 75 microns (CSB)
Bran Product 8480	100	95.2	99.1	80.4	52.9
Yellow Corn Flour 4300	100	99.9	98.4	72.6	48.2
Fine Yellow Corn Bran 8010	100	97.0			
Low Moisture Pregel Flour 7403[c]	100	95.0			
Medium Viscosity Flour 4407	>99.9	71.0			
Yellow Corn Bran 8000	65	5.0			
Torit Filter			97.7	82.9	71.0
4D Filter			100	97.0	85.9

As shown in **Table 2** above, of the samples the CSB collected, at least 97% of each sample was smaller than 425 microns. Didion's product specifications indicated that five of the six products for which the CSB could obtain data contained only trace amounts of particles larger than 425 microns. Numerous product streams in A Mill, B Mill, and D Mill indicated as smaller than 425 microns on Didion's process flow diagrams. Given that finished or nearly finished products were leaving the mill buildings and being transported to Bulk Loadout and packaging areas, much of the mill facility contained combustible dust, even by the historical NFPA definition.

Despite the warnings published in its SDSs and the product particle size data Didion published, Didion did not treat many of its products or intermediate process streams as containing combustible dust hazards. This is demonstrated by Didion responses during a 2013 OSHA inspection, as well as responses to various insurance inquiries, in which Didion stated as much. For example, in 2013, Didion's Safety and Environmental Manager noted that "the particle size is too large to get an explosive atmosphere" in the Torit Filter, in response to an insurance inquiry. As noted in **Table 2** above, the CSB's Torit Filter sample testing indicated that more than 97% of the material in the Torit Filter was smaller than 425 microns, making it well below the particle size threshold for combustible dust.

[a] Typical particle size data for the 8480 Bran product was derived from averages of lab results from a February 2017 production run of 8480.

[b] Didion measured particle sizes as a *weight* percentage of samples below a set screen size. A different particle size measurement, reported by *volume* percentage of samples below a set size, was used in the testing commissioned by the CSB. For similar materials with constant density throughout the size distribution, as in this case, the two measurements are comparable.

[c] Didion defined Pregel material as "corn meal and corn flour that is cooked at high temperature under pressure then ground to a flour".

Dust Combustibility Data

In addition to requesting data for dust characteristics from Didion, the CSB commissioned independent explosibility testing for the collected samples following the incident. These samples were assessed using dust explosibility test standards[a] established through ASTM International[b] (ASTM). These analyses included standardization of sample moisture content and particle size to less than 5% moisture by weight and 75 microns, respectively. The samples were dried, milled, or sieved as required prior to testing for dust combustibility. The technical basis for the CSB testing protocols is presented in **Appendix F**. The CSB explosibility data report from the testing laboratory is presented in **Appendix G**.

The CSB test results indicated that all Didion products and in-process materials tested qualified as combustible dust ($K_{St} > 0$). The results were consistent with other available published data for corn materials and the properties published in Didion's SDSs. **Table 3** below compares some CSB dust explosibility results with values reported in Didion SDSs, NFPA published data for corn, and other common dusts for context.

[a] These test standards use the term "explosibility" to describe the properties they test for. For the purposes of consistency in this report, explosibility and combustibility will be considered synonymous.

[b] Formerly the American Society for Testing and Materials and started in 1898, ASTM International is "one of the world's largest international standards developing organizations" and is a "globally recognized leader in the development and delivery of voluntary consensus standards [92]."

Table 3: Comparison of select combustible dust properties from CSB testing, Didion SDSs, and NFPA 68 (2007 edition) [48, pp. 63-65]. (Credit: CSB)

Data Source	Mass Median Diameter (microns)	Pmax [bar(g)]	KSt (bar m/s)	MEC (g/m^3)
CSB Testing – Bran Product 8480, <5% moisture	29	8.2	137	60-75
CSB Testing – Torit Filter, <5% moisture	18	8.1	158	70-80
Didion SDSs	NR[a]	7.9	180	120-140, also 55
NFPA 68 (2007), Corn	28	9.4	75	60
NFPA 68 (2007), Starch, Corn	7	10.3	202	NR
NFPA 68 (2007), Sugar	30	8.5	138	200
NFPA 68 (2007), Coal, bituminous	24	9.2	129	60
NFPA 68 (2007), Polypropylene	25	8.4	101	30
NFPA 68 (2007), Aluminum	29	12.4	415	30

The CSB concludes that Didion did not accurately assess the number of process streams in the mill buildings that contained combustible dust. Didion did not fully recognize the combustible dust hazards of its materials, resulting in a lack of combustible dust safeguards, which directly led to the incident.

4.1.2 Equipment Interconnectivity

Process Manifolding at Didion

As described in **Section 3.1**, during the incident, a deflagration propagated to the Dry Grit Filter, severely burned and overpressured the Dry Grit Filter housing, and further propagated throughout the facility rapidly via the highly interconnected ductwork system. Consequently, deflagrations and fires were able to propagate throughout the ductwork to other equipment and processes, such as the Grit Dryer system in D Mill (**Section 3.1.4**).

Didion connected numerous pieces of equipment together, including mills of various types, as shown in **Figure 45** below. For example, the CSB estimated that the Dry Grit Filter connected at least 46 pieces of equipment across at least four different processes and three buildings. This heavily manifolded system design, without any form of isolation controls present to mitigate or stop a propagation event, increased the propagation risk at Didion. As shown in **Figure 45**, once a propagation began in this system, it could continue to spread through multiple buildings and processes (represented by different-colored boxes) quickly given the interconnectivity the Dry Grit Filter provided. As discussed below in **Section 4.9**, OSHA alerted Didion to this hazard more than three years before the incident. The engineering controls for propagation risk mitigation are further discussed in **Section 4.3**.

[a] Not reported

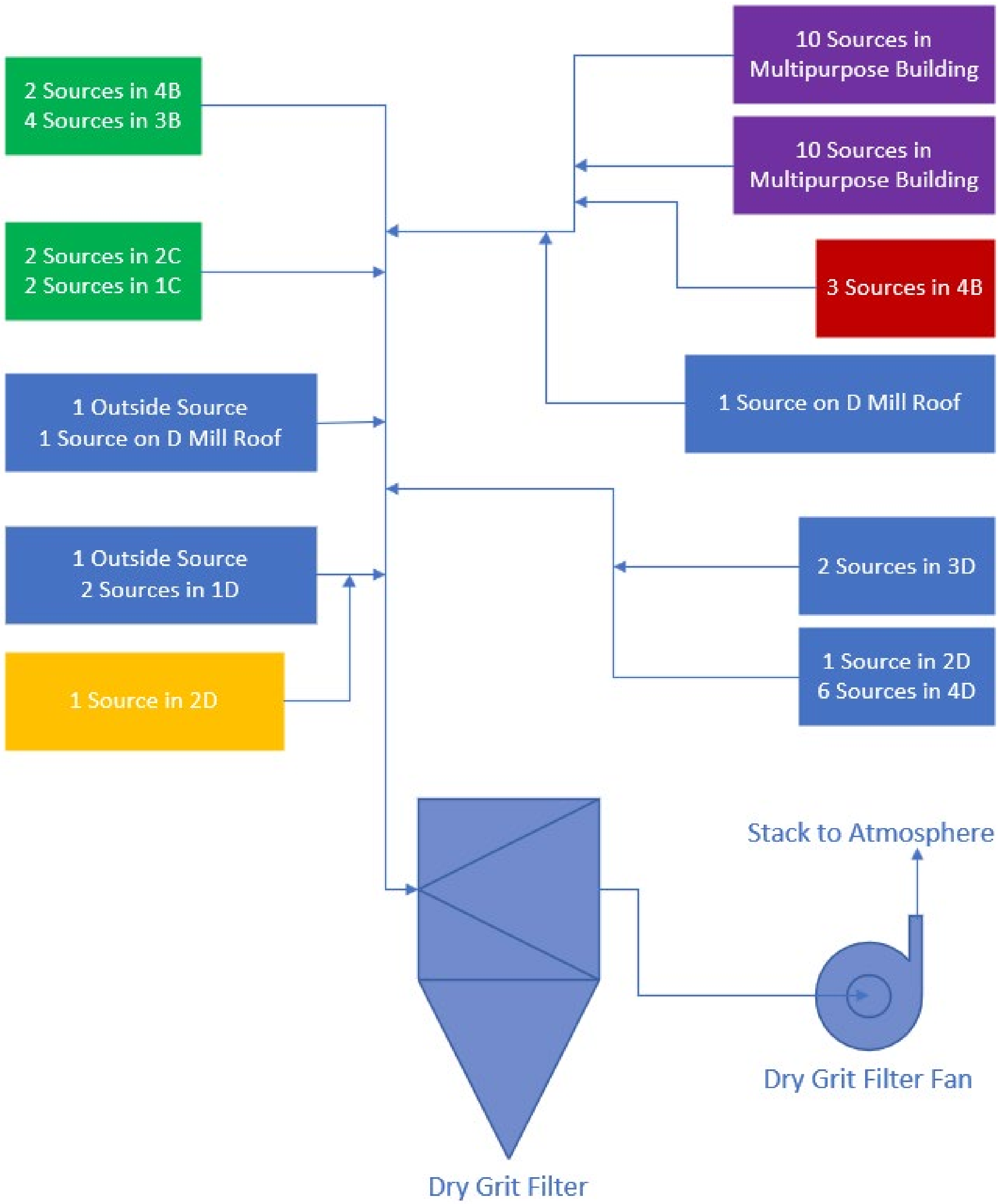

Figure 45: Diagram of sources for the Dry Grit Filter. Each mill facility process is represented by a different-colored box. (Credit: CSB, adapted from Didion)

The CSB concludes that Didion did not recognize the propagation hazard that interconnecting numerous pieces of equipment presented and did not take sufficient action to prevent flame front propagation through its dust collection systems. This lack of recognition increased the likelihood that a propagation

event could occur and allowed what could have been a localized fire and dust explosion to propagate throughout the facility.

Industry Guidance

Several NFPA standards contain guidance regarding connecting dust collectors to processes and manifolding ductwork, including NFPA 61, 91, 652, and 654. As early as 2008, NFPA 61 (2008-2020) stated that "[d]ust collection systems for one or more hammer mills or pulverizer mills shall not be manifolded with other types of machinery [47, p. 13] [6, p. 16] [23, p. 19]."[a]

NFPA 61 (2008 through 2020 editions) also references NFPA 91 *Standard for Exhaust Systems for Air Conveying of Vapors, Mists, and Particulate Solids* regarding duct systems for air-material separators. NFPA 91 (2010-2020 editions) requires:

> Ducts from a single piece of equipment or from multiple pieces of equipment interconnected on the same process stream shall be permitted to be manifolded. […] Ducts from nonassociated pieces of equipment shall be permitted to be manifolded provided that each duct is equipped with an isolation device prior to manifolding in accordance with NFPA 69, *Standard on Explosion Prevention Systems* [49, p. 11] [50, p. 13] [51, p. 7.1.9.2].

FM Global guidance warns against connecting multiple processes into a common dust collection system, regardless of the presence or absence of any isolation devices:

> Use a separate dust collection system for each process area to minimize the chance of a dust explosion and fire involving many operations. If a large collection capacity is needed, consider the use of multiple smaller collectors, instead of one large collection unit [52, p. 3].

The CSB concludes that had Didion limited the equipment interconnectivity through its dust collection systems, the initial deflagration on 1B could not have propagated throughout the process equipment so easily, which could have reduced the severity of this event.

4.1.3 DUST COLLECTOR EXPLOSIBILITY

Didion's Dust Collector Calculations

Didion provided combustible dust calculations to OSHA and its insurance carrier in 2013, and to the CSB after the incident. The calculations indicated that the dust concentrations inside all mill facility dust collectors were below the MEC. Among these calculations, the maximum dust concentration calculated was 12% of MEC within the air streams supplying Didion's dust collectors.

Didion calculated the dust concentration inside each dust collector by:

- measuring or calculating an air flowrate supplying each dust collector;

[a] While not directly causal to this incident, Didion did violate this standard in several locations, tying hammer mills, roller mills, and gap mills into its dust collection systems with other types of equipment.

- measuring or calculating solid particles flowrate in the ductwork feeding each dust collector;
- removing any particles sized greater than 425 microns from the calculation;
- using the resulting airflow and particle flow values to calculate a dust concentration in the supply duct to the dust collector; and
- comparing the resulting concentration to the MEC.

An example calculation is shown in **Figure 46**.

From nclabor.com page 11 table 1	http://www.nclabor.com/osha/etta/indguide/ig43.pdf				
Lower explosive limit for corn dust.					
55	grams/M3				
Granulation	1	2	3	Average	NFPA 61
40 Wire	95.2%	96.0%	93.2%	94.8%	
Pan	4.8%	4.0%	6.8%	5.2%	
Material flow					
17500	Lb/hr gross mass flow rate thru 6 filters				
910	Lb/hrflow rate of less than 40 wire				
910*453.59237=					
412,769.06	Grams/hr				
Air flow					
63549	acfm				
63549*0.028316846592*60=					
107970	cubic meters/hr				
412769.06	/107970.437=				
3.82	grams/M3				
7.0%	Percentage of lower explosive limit.				

3.3 General Definitions.

3.3.1* Agricultural Dust. Any finely divided solid agricultural material 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) that presents a fire or explosion hazard when dispersed and ignited in air.

3.3.2* Air-Material Separator (AMS). A device designed to sepa-

Figure 46: Example dust explosibility calculation for the Dry Grit Filter. (Credit: Didion)

These calculations led Didion to conclude "with a wide safety margin that the process does not present an explosion hazard" and with regard to the Dry Grit Filter that "the new grit filter and all associated ductwork are also well below the lower explosive limit and doesn't present an explosion hazard."

Dust Collector Explosibility Guidance

As mentioned in **Section 2.2.3**, Didion's processes included several dust collectors. Dust collectors are the equipment most commonly involved in dust explosions [8, p. 32]. As such, they require special consideration with regard to combustible dust hazard mitigation.

While in normal operation, dust accumulates on the outside of the filter media elements. Dust must then be removed from the outside of the elements to clean them off [38, pp. 30.10, 30.12]. A common way to clean filter media elements is using a pulse jet, which was used in the Dry Grit Filter and Torit Filter.[a] During a pulse jet, a

[a] Although the Torit Filter had paper-like cartridges to filter dust rather than flexible bags as described above for baghouses, the operating principle is the same.

compressed air jet operating for a fraction of a second dislodges the accumulated dust [38, p. 30.13]. The reverse-flow pulse breaks up the dust layer on the outside of the bag, and dislodged material eventually falls to a hopper, as shown in **Figure 47** below [38, p. 30.14]. This is performed on a small percentage of filter media elements at one time, and in turns, so that all elements are cleaned relatively frequently and while the dust collector remains in operation.

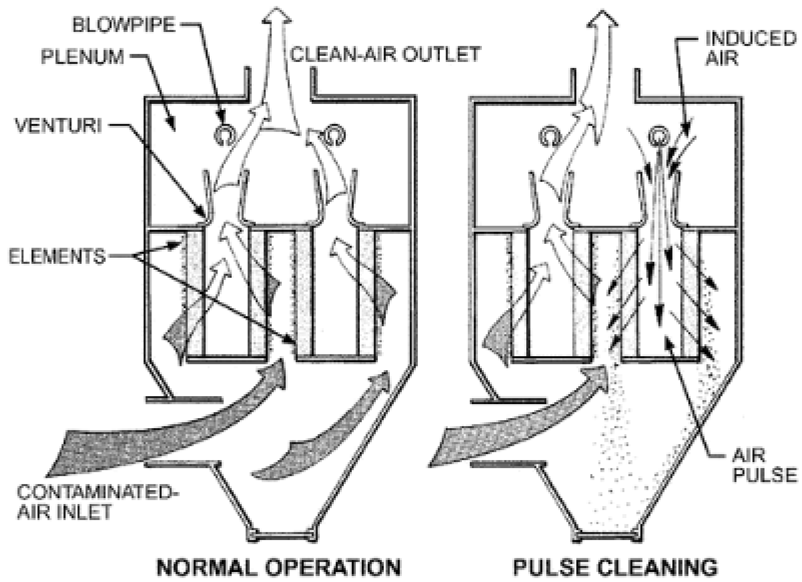

Figure 47: Normal operation (left) and pulse jet cleaning (right) in a dust collector [38, p. 30.14]. (Credit: ASHRAE)

The pulse jet cleaning operation can present a further combustible dust hazard to manage. CCPS's *Guidelines for Combustible Dust Hazard Analysis* explains why this is so:

> The dust concentration in at least a portion of the collector is usually above the MEC. The finest particles of the dust, which may have a lower MIE and higher K_{St} than the bulk of the dust, are collected in the baghouse. […] In addition, there is a high potential for explosion propagation upstream and downstream. Pulsing or shaking of filters can lead to transient combustible dust clouds above MEC [8, p. 32].

FM Global Property Loss Prevention Data Sheet 7-73, *Dust Collectors and Collection Systems* (2020), also points out that:

> There are differences between the filter media, but, from a protection standpoint, if combustible dusts are collected, there is a fire and explosion hazard in the collector regardless of filter construction [52, p. 14].

Combustible dust hazards are inherent in dust collector design and are particularly prominent in pulse jet type dust collectors such as the Dry Grit Filter. The ACGIH *Manual of Recommended Practice for Design* states:

> Because media-based collectors develop dust cakes on the surface of the media, the concentrations of dust present at the media when the dust cake is disrupted will be much higher than concentrations of dust in the inlet duct to the collector [27, p. 8.8].

Sampling dust collectors for hazardous dust also requires careful execution; the dust concentration and particle size distribution are not uniform throughout the dust collector. The proportion of fine particle sizes tends to be underestimated in the material exiting the bottom of the dust collector and the supply stream(s) feeding the dust collector, as compared with the fine dust that collects on the filter media [27, p. 12.6]. The ACGIH *Manual of Recommended Practice for Design* further states:

> … a sample of dust from the material discharge of the dust collector may be significantly less explosive than fine dusts lying on horizontal surfaces above a process area within the facility. Using combustion data from dust samples taken only from the material discharge of the collector may give design engineers a false sense of security relative to the potential explosivity of dusts present in their process. As an alternate, the dust collected on the filters themselves may better represent the fine dusts that present a more severe explosion risk [27, p. 12.6].

Neither NFPA 652 nor NFPA 61 contain requirements regarding validating that a combustible dust concentration above MEC exists in dust collectors. The 2016 edition of NFPA 652 contains optional guidance:

> Dust collection systems for combustible dusts represent a significant increase in deflagration risk compared to most pneumatic conveying systems. This is due to the inherent design and operational characteristics of dust collection systems. A properly designed system is critical to minimizing that risk. For guidance on determining proper dust collection system design refer to ACGIH, *Industrial Ventilation: A Manual of Recommended Practice* [46, p. 50].

Available industry guidance does not detail how to perform dust concentration calculations inside dust collectors as Didion's calculations attempted to do. Rather, the guidance focuses on presuming a dust concentration above MEC will be present inside most dust collectors and mitigating that hazard. Whether from normal pulsing events to clean the filter media or from upset conditions, the nature of dust collectors is to concentrate fine dusts, and the safe approach is to assume that MEC will be achieved inside a dust collector at some time.

Didion made several critical errors that led to its mistaken conclusion. In general, Didion's calculations incorrectly assumed that:

- the concentration of the feed stream to the dust collector was representative of the concentration inside the dust collector itself;
- the particle size distribution Didion used was representative of the material inside the dust collector;
- no material over 425-micron particle size was combustible and thus could simply be ignored;
- steady-state operation was always accurate and there was no need to account for changes, upset, or transient conditions; and
- all supply ductwork and dust collector surfaces were always clean, with no material accumulation.

The details regarding and technical basis behind each of these errors are documented in **Appendix C**.

The CSB concludes that Didion's dust collector calculations were incorrect and that the Dry Grit Filter did contain an explosive dust concentration on the night of the incident, as evidenced by the Dry Grit Filter explosion. Had Didion acted upon this hazard, the incident consequences could have been reduced.

The CSB concludes that Didion's incorrect calculations contributed to the lack of recognition that most dust collectors, by their nature, contain an explosive dust concentration. Had Didion acted upon this hazard, the incident consequences could have been reduced.

The CSB recommends that Didion install explosion and propagation mitigation systems to protect its dust collection systems, presuming a dust concentration above MEC inside its dust collectors. Didion should ensure its dust collection systems are properly designed using available guidance such as that provided by ACGIH, CCPS, and FM Global and correct any current design deficiencies. At a minimum, Didion should incorporate into its designs that:

- **a. Most dust collectors contain combustible dust concentrations above MEC, particularly during cleaning events; and**
- **b. The finest dust particles, which may have a lower MIE and higher K_{St} than the bulk of the dust, are concentrated in dust collectors.**

4.1.4 Transport Velocity and Pressure Balance

A critical variable for proper operation of a pneumatic conveyance or dust collection ductwork system is transport velocity [27, p. 5.2]. Transport velocity is the air flow rate through the equipment and ducting that is required to maintain solids entrainment during the transport between pieces of equipment. If the transport velocity is too low, solids begin to deposit and accumulate within the equipment and ducting, presenting a fire and explosion hazard.

In a multi-branch system design, it is also necessary to properly balance the static pressure[a] for each duct segment at the junction [27, p. 4.9]. The ACGIH notes in its *Manual of Recommended Practice for Design*:

> Air will always take the path of least resistance. If the designer makes no attempt to balance the static pressure in a multi-branch system, a 'natural balance' will occur at each junction. This 'natural balance' will result in an undesirable modification to the flow rate of each segment […] thereby impacting the […] ability to successfully capture and convey the desired contaminant. Therefore, the designer should take appropriate steps to balance static pressures at all branch junctions. Properly doing so will ensure that the design airflow […] does not fall to its minimum [27, p. 4.9].

[a] ACGIH defines static pressure as the potential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow. [27, p. xii]

This flow and pressure balance can be achieved or adjusted by a number of strategies, including ductwork sizing and a series of adjustable dampers coupled with flow measurements while the system is operating. The goal is to ensure the static pressure is balanced across all branches, while each branch has adequate airflow to maintain at least minimum transport velocity [27, p. 4.9].

After the incident, the CSB identified multiple locations, including Dry Grit Filter and Torit Filter supply ductwork, containing corn product accumulations, as shown in **Figure 48** and **Figure 49** below. This is evidence of insufficient transport velocity: areas of dangerous dust accumulation inside ductwork indicates the minimum velocity could not be maintained in those areas. In some areas the accumulations inside ductwork were several inches thick, which was well beyond what would be expected simply from the mill facility losing electric power during operation.

Key Lesson

Companies should ensure pneumatic transport and dust collection ductwork is designed to maintain a minimum transport velocity, and companies should determine what the appropriate minimum velocity should be, based on the characteristics of their dust. The minimum transport velocity must be maintained to prevent the accumulation of material in process equipment and ducting.

The determination of minimum transport velocities is discussed in NFPA 61, *Standard for the Prevention of Fire and Dust Explosions in Agricultural and Food Processing Facilities,* NFPA 652, *Standard on the Fundamentals of Combustible Dust*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*.

Figure 48: Dry Grit Filter supply ducting post-incident (right) with corn product accumulation (inset). Material fell out of ductwork during demolition. (Credit: CSB, adapted from EFI)

Figure 49: Torit Filter supply ducting with material deposits inside. (Credit: CSB)

The settled corn material inside ductwork is combustible fuel within the system that, upon dispersion, can present subsequent deflagration hazards. As the pressure wave propagates through the ducting from the deflagration origin, the settled corn material is disturbed and dispersed inside the duct. As described in **Section 1.2**, the following flame front can then ignite the mixture of air and corn material to continue the propagation of the event throughout the process.

NFPA Guidance

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Dust Particulate Solids*, provides a minimum velocity to transport particulate solids. NFPA 654 (2013) states:

> A velocity of 4000 fpm [feet per minute] (20 m/s) is recommended as a minimum value for the conveying of combustible dusts. Also, some combustible dusts have material characteristics (e.g., cohesiveness, adhesiveness, particle shape and size, particle density) that require significantly higher duct velocities to minimize the possibility of accumulations in the ducts [53, p. 36].

Specific to agricultural dusts, NFPA 61, *Standard for the Prevention of Fire and Dust Explosions in Agricultural and Food Processing Facilities* (2017-2020 editions) states in (optional) Annex A regarding dust collection systems: "Maintaining adequate duct velocity (usually 4000 fpm or higher) is a key factor in the proper functioning of the system." This information is not in the main body of the standard, however [6, p. 30].

NFPA 652 does not specify a quantitative value for minimum transport velocity but does require that the velocity be sufficient. For pneumatic conveying, dust collection, and centralized vacuum cleaning systems, NFPA 652 requires that:

> The system shall be designed and maintained to ensure that the air-gas velocity used shall meet or exceed the minimum required to keep the interior surfaces of all piping or ducting free of accumulations under all normal operating modes [46, p. 18].[a]

Didion provided to the CSB documentation of what appeared to be a one-time calculation[b] of transport velocities throughout dust collectors in the mill facility. This was part of Didion's effort to calculate dust concentrations in dust collectors, described above in **Section 4.1.3**. Didion's ductwork velocity calculations show multiple systems with transport velocities well below the 4000 fpm recommended by NFPA 61 and 654. **Figure 50** shows the calculation for Dry Grit Filter ductwork as an example. Note that this calculation represents only the main system branches, since as discussed above, the Dry Grit Filter ductwork system contained branches to at least 46 pieces of equipment.

F6 Grit Filter					
Pipe #	Velocity(ft/min)	Diameter (in.)	Area (ft^2)	Volumetric Flow (CFM)	
1	2000	36	7.0685775	14100	
2	2800	12	0.7853975	2200	
3	2800	20	2.181659722	6100	
4	200	16	1.396262222	300	
5	4000	16	1.396262222	5600	
6		36	7.0685775	12000	
7	6000	5	0.136353733	800	
8	2000	5	0.136353733	300	
9	2300	42	9.621119375	22100	
10		42	9.621119375	22400	
11	9300 ~~4100~~	16	1.396262222	5700	
12	Total Cfm grit filter	42	9.621119375	~~57200~~	60900
Total filter cfm capacity				75000	
total available cfm				~~17000~~	14100

Figure 50: Example of transport velocity calculations (red box) from Dry Grit Filter ductwork branches (Stream 11 is incorrectly calculated). Note values below 4000 fpm. (Credit: Didion, annotations by CSB)

The CSB concludes that Didion did not follow industry guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, or NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, in designing pneumatic transport or dust collection system ductwork and did not ensure adequate transport velocity throughout the facility. This unrecognized hazard likely resulted in significant combustible material deposits inside ductwork systems and potentially contributed to flame front propagations throughout the process ductwork during the incident.

[a] This same language was added to NFPA 61 in the 2020 edition [23, p. 19].

[b] Didion supplied these calculations to OSHA in 2013.

The CSB recommends that Didion contract with a competent third-party contractor to design and install pneumatic conveying and dust collector ductwork systems in accordance with guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, taking into account the minimum required transport velocity.

4.1.5 Ductwork Changes

Any changes to ductwork systems also changes airflow and static pressures inside the ductwork system. According to the ACGIH *Manual of Recommended Practice for Design*, a balanced industrial ventilation system is one in which, among other things, “Transport (Conveying) Velocity is maintained in all branches and main lines carrying air.”

NFPA Guidance

For duct systems, NFPA 61, *Standard for the Prevention of Fire and Dust Explosions in Agricultural and Food Processing Facilities* (2017), requires that “[d]ucts that handle combustible dust particulate solids shall conform to the requirements of NFPA 91” with some amendments not relevant here [6, p. 17].

NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids* (2010 edition), in turn, has several requirements for branching or changing ductwork: [49, p. 8] [51, p. 4.5.12]

> Additional branch ducts shall not be added to an existing system without redesign of the system. […] Branch ducts shall not be disconnected nor unused portions of the system be blanked off without provision for means to maintain required airflow.

Guidance was also available in NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Dust Particulate Solids* (2013):

> [e]xisting systems shall not be modified without considering the effects of those changes on the system performance, including the redesign of the system to incorporate the proposed changes [53, p. 15].
>
> […]
>
> Modifications to the [pneumatic conveying, dust collection, and centralized vacuum cleaning] system can significantly change the ability of the system to provide the original design performance. An analysis of any proposed changes should be done in accordance with Section 4.3 [concerning management of change] to ensure the system will still be able to meet safety and performance requirements [53, p. 35].

While Didion did perform a one-time set of calculations that included transport velocity, subsequent process changes at the mill facility did not appear to trigger a reassessment of these calculations. As discussed below in **Section 4.6**, there is no evidence that Didion evaluated pneumatic transport or dust collection systems design changes to ensure a minimum transport velocity was available throughout the systems, nor that the systems had been rebalanced after the changes were made. Multiple changes added new equipment that required connection to a dust collector or changes to pneumatic transport piping, but this was not addressed in the change documentation.

Based upon the photographic evidence of ductwork deposits in **Figure 48** and **Figure 49** and Didion's own transport velocity calculations, the CSB found no evidence that Didion accounted for ductwork changes or the detrimental effects on the transport velocity these changes could cause.

The CSB concludes that Didion did not follow industry guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids*, or NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, when making modifications to pneumatic transport or dust collection system ductwork and did not ensure adequate transport velocity throughout the facility. This unrecognized hazard resulted in significant combustible material deposits inside ductwork systems and contributed to deflagration propagations throughout the process ductwork during the incident.

4.1.6 Ductwork and Dust Collector Inspections and Cleaning

Even in the best designs, process upsets and unintended consequences of planned changes can create dust accumulations over time in pneumatic conveying and dust collection equipment.

Didion maintained an electronic work order system to track maintenance work. The CSB received thousands of work order records from Didion, many of which were preventive maintenance (PM) tasks for various processing equipment. The CSB reviewed all work orders from 2015, 2016, and 2017 received from Didion but could not identify any work orders as PM tasks that concerned inspection for accumulation or cleaning dust collectors or associated ductwork, including the Torit Filter or the Dry Grit Filter. The CSB also could not identify any non-routine or one-time cleanouts or inspections that addressed any dust accumulations in dust collectors or associated ductwork in the Didion work order system or in any available shift logs.

Additionally, Didion's Master Sanitation Schedule did not mention any dust collectors or ductwork associated with them on any of the cleaning frequencies. Similarly, the Monthly Sanitation Inspection did not mention dust collectors nor any supply ductwork to dust collectors as subjects for inspection.

After the incident, the CSB observed evidence of accumulated material in ductwork supplying the Dry Grit Filter and the Torit Filter, and inside the Torit Filter chamber. Because the inside of the Dry Grit Filter was completely burned, including the filter bags, no assessment of residue could be made there. Enough material had accumulated to fuel sustained fires in some locations, such as Dry Grit Filter ductwork (**Figure 51**).

Figure 51: Dry Grit Filter ductwork on fire (red arrows) hours after the explosions. Inset: close-up of ductwork. (Credit: Columbia County Sherriff's Department, annotations by CSB)

Industry Guidance

For dust collectors to function properly, periodic inspection and maintenance are necessary. Issues to check for in dust collectors include:

- coating on bags that cannot be removed by on-line cleaning;
- material accumulations on the chamber wall and in the dust hopper;
- coating thickness variations along the length of filter elements;
- color of material for signs of smoldering, heat, or microbial growth; and
- damage or wear to filter bags or cages [36, p. 731].

Likewise, the ductwork supplying these dust collectors should also be periodically inspected and cleaned to prevent combustible dust accumulation [12, p. 314]. Accumulations in ductwork are ready fuel for a propagation, as described in **Section 1.2**.

FM Global provides a loss prevention data sheet (7-78) on the use of industrial exhaust systems, which is applicable to dust collectors and associated ductwork used in the Didion milling process. FM Global warns:

> A poorly maintained industrial exhaust system without regular filter maintenance or the presence of deposits can lead to a decrease in airflow. The decrease in airflow will allow deposits to accumulate within the ductwork, due to lack of proper entrainment of the fume or particulate in the airflow. The longer deposits are allowed to build up, the more combustibles available for fire propagation. These deposits can sometimes spontaneously combust or if ignited becomes fuel to feed and quickly spread a fire throughout the industrial exhaust system. Deposits are hidden, and the hazard can often be overlooked. The inspection and maintenance of industrial exhaust systems

is important to ensure proper operation of both the fire protection and the exhaust system, and that deposits are not building up. If deposits are found, it is necessary to clean the ductwork and review airflow velocities for proper design and operation [54].

FM Global's recommendations for monitoring and inspections include:

- Industrial exhaust systems should be designed by licensed professional engineers experienced in the design and construction of such systems.
- Quarterly visual inspections of ductwork, equipment, and fire protection components should be conducted to identify excessive combustible deposits. Deposits exceeding 1/8-inch accumulation should be cleaned to mitigate potential fire hazards.
- Further guidance is given to increase or decrease inspection frequency based upon findings over a one-year cycle to prevent the accumulation of material in excess of 1/8-inch at any time between cleaning cycles.
- Monitor airflow velocity and provide a low airflow alarm to notify personnel of the need to change filters or other media at 95% of the design velocity or as specified by the designer.

Since 2004, NFPA 91 has required that ducting in pneumatic conveyance systems be maintained and inspected. Duct inspections include monthly visual inspections for material accumulations inside the ducting to prevent impacts to the system. Subsequent updates of the NFPA standard in 2010 and 2015 include requirements to retroactively implement the inspection programs.

Didion did not provide to the CSB any evidence that ductwork or dust collectors were periodically inspected or cleaned for combustible dust deposits.

The CSB concludes that despite guidance to the contrary, Didion had no cleaning or inspection program to remove combustible dust accumulations from dust collectors or pneumatic conveying systems. As a result, significant combustible dust deposits inside ductwork were present on the night of the incident. This allowed a localized process fire to propagate throughout the mill buildings and processes the night of the incident.

The CSB recommends that Didion implement a periodic inspection and testing program for pneumatic conveying and dust collector ductwork systems, following industry guidance such as NFPA 91 and FM Global publications. The program should include cleaning on a set frequency and measuring transport velocities on a routine basis to ensure proper system function.

4.1.7 OSHA Requirements

OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, has no requirements relating to combustible dust testing, assessing combustible dust hazards, process interconnectivity, or design guidance for dust collectors, pneumatic conveying or ductwork systems, or transport velocity. As discussed in **Section 4.1** above, had OSHA required any of these items, and Didion performed them, the incident could have been prevented or mitigated. The *Grain Handling Facilities Standard*, 29 CFR § 1910.272(m), does require some preventive maintenance, such as regularly scheduled inspections of dust collection equipment, lubrication and other appropriate maintenance in accordance with manufacturers' recommendations, and prompt correction of "dust collection systems which are malfunctioning or which are operating below designed efficiency," but does not address transport velocity or accumulations of combustible dust inside dust collectors or their supply ductwork.

The CSB concludes that the OSHA *Grain Handling Facilities Standard* does not address the process design considerations that could mitigate combustible dust hazards, such as those that resulted in the fires and propagations during the Didion incident.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates equipment and process design considerations, such as the NFPA 61 Chapter on Hazard Identification and the applicable ductwork design requirements in NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids*.

4.2 Dust Hazard Analysis

A DHA is defined as:

> A systematic review to identify and evaluate the potential fire, flash fire, or explosion hazards associated with the presence of one or more combustible particulate solids in a process or facility [46].

In 2014, Didion's Safety and Environmental manager became aware of the requirements for hazard analyses for combustible dust and the retroactive requirements when NFPA released the draft version of NFPA 652. These requirements were also shared with other senior managers and one of the owners. In 2016, the Didion environmental manager again raised the need to meet the requirements of NFPA 652 to Didion safety and operations management and provided a summary of the requirements of the standard, including DHAs. In April 2017, Didion began to search for a third party to assist with DHAs; however, no party had been selected at the time of the incident. Didion had not performed any DHAs to identify or address potential combustible dust hazards when the incident occurred.

4.2.1 Dust Hazard Analysis Guidance

NFPA added the requirement for DHAs as part of the updates to NFPA 652, *Standard on the Fundamentals of Combustible Dust*, in 2015. The implementation of DHAs was not required to be completed until 2018. The implementation of DHAs required reasonable progress in each of the three years prior to the implementation deadline [46]. The 2017 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, extended the deadline for DHA completion to 2021 [6].[a] The 2020 edition of NFPA 61 extended the deadline again to January 1, 2022 [23].

Didion used the changes in the deadline to the implementation of the DHAs to delay compliance with the NFPA standards. In 2016 emails, Didion management focused on the compliance date, stating, "…we have about 2.5 years to come into compliance."

[a] NFPA allows the use of the industry- or commodity-specific NFPA standard requirements when differences arise between those standards and NFPA 652. [46]

The CSB concludes that Didion's delayed implementation of Dust Hazard Analyses (DHAs) prevented the assessment of the mill processes for potential combustible dust hazards in a timely manner and implementation of safeguards that could have prevented or mitigated the severity of the incident.

To determine the engineering controls needed to mitigate a combustible dust explosion, the NFPA concluded that a facility should evaluate the potential hazards that can be experienced when handling combustible dust through the performance of DHAs. The 2016 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, explained that DHAs should assess, "[e]ach and every process component […], including ducts, conveyors, silos, bunkers, vessels, fans and other pieces of process equipment." The 2017 edition of NFPA 61 limits the scope of DHAs to certain types of equipment, such as: bucket elevators, conveyors, grinding equipment, spray dryer systems, and dust collection systems [6, p. 13]. The limited scope of DHA assessments in NFPA 61 does not require the assessment of equipment that was involved in the incident such as cyclones, fans, and pneumatic conveying ducts.

The CSB concludes that NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, does not cover all equipment that could have the potential for combustible dust hazards. As a result, hazards presented by the uncovered equipment could go unassessed. Had Didion been required to assess all of the process equipment, including the cyclones, pneumatic conveying systems, and rotary valves, as required by NFPA 652, *Standard on the Fundamentals of Combustible Dust*, Didion could have identified potential smoldering fire and explosion hazards in the equipment where the smoldering fire and first explosion likely occurred.

The CSB recommends that the NFPA update the DHA requirements in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Process Facilities*, and all successor standards, to include the requirements of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, including ducts, conveyors, silos, bunkers, vessels, fans, and other pieces of process equipment in its requirements for the performance of dust hazard analyses.

4.2.2 Reconstruction Dust Hazard Analyses

Didion performed DHAs during the design phase of the mill facility reconstruction following the incident. In the documentation of the DHAs performed during the reconstruction of the mill facility, there are references to spark detection systems, deflagration suppression systems, and deflagration venting systems. These documents, however, were preliminary design documents. The DHAs included recommendations to install pre-deflagration spark detection systems, deflagration suppression systems, deflagration venting systems, deflagration isolation systems, and deflagration containment. Didion did not have a system in place to ensure that the recommendations were implemented. Furthermore, Didion had no corrective action plans in place to correct the deficiencies or implement the recommendations specified in the DHA.

DHA reports generated following the DHA studies highlighted the number of scenarios that could lead to a combustible dust fire or explosion. In these reports, some of the process designs and equipment installations do not meet the engineering design requirements of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*. These scenarios include a lack of explosion protection and suppression systems for the milling equipment identified in the DHA scenarios involving explosions in mills and the subsequent propagation through the equipment. One DHA report summarized some of the gaps as follows:

> There are several scenarios where the current plans for equipment protection are not consistent with NFPA 61 requirements. One example is the lack of an explosion protection/suppression system for the [hammer] mills…

While the new mill facility design included the installation of rotary airlocks designed to meet the requirements of isolation, notes provided by Didion indicated that "many of the airlocks have too large of a clearance to be considered isolation." The reconstructed facility DHA recommends verifying compliance with NFPA 69, *Standard on Explosion Prevention Systems*, and the need for preventative maintenance to verify the gap required to meet NFPA 69 for rotary airlocks to meet isolation requirements. One recommendation issued in the DHA was to ensure that the design pressure of equipment could withstand elevated pressure if chemical suppression could not be installed.

Key Lesson

To ensure effective prevention and mitigation of combustible dust deflagrations, engineering controls (detection, suppression, isolation, venting, and pressure containment) must be utilized in conjunction with one another when designing a dust safety system.

The CSB concludes that while Didion performed dust hazard analyses on the reconstructed mill, Didion did not implement deflagration controls that could have prevented the 2017 incident. The analysis performed by Didion contained potential gaps in the reconstructed facility that do not comply with the NFPA requirements for deflagration engineering protections and controls, which would not prevent the reoccurrence of an incident, such as the one in 2017.

The CSB recommends that Didion perform DHAs on all buildings and units that process combustible dust. Ensure that the DHAs are revalidated at least every five years. Implement pre-deflagration detection, deflagration venting, deflagration suppression, deflagration isolation, and deflagration pressure containment engineering controls identified in the initial and revalidation DHA in accordance with NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, NFPA 69, *Standard on Explosion Prevention Systems*, and NFPA 652, *Standard on the Fundamentals of Combustible Dust*.

4.3 Engineering Controls for Combustible Dust Hazards

During the incident, once the smoldering fire transitioned to an explosion, the combustible dust fires and explosions propagated through process equipment. The South BM Cyclone exhibited rupture damage likely due to the initial explosion within the equipment. The lack of engineering controls on the equipment allowed propagation throughout the facility. Engineering controls can prevent or mitigate combustible dust deflagrations by limiting the spread of fire or extinguishing the flames during the incident. As described in **Section 1.4**, engineering controls are listed in the middle of the hierarchy of controls and can be either active or passive controls.

The CSB requested information from Didion for engineered controls for combustible dust hazard management, including dust collection systems, dust suppression systems, and deflagration venting equipment. The CSB also requested "all documentation pertaining to the design, installation, and maintenance of the dust collection systems at the Didion mill facility." Didion was unable to provide evidence of the presence or use of any such systems.

4.3.1 NFPA Guidance on Deflagration Engineering Controls

The NFPA provides guidance on a number of deflagration controls for combustible dust explosions. NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, and NFPA 69, *Standard on Explosion Prevention Systems*, cover several potential engineering controls to prevent explosions. These controls, which could have prevented or reduced the severity of the incident at Didion, include:

- Pre-deflagration Detection (**Section 4.3.1.1**)
- Deflagration Control by Isolation (**Section 4.3.1.2**)
- Deflagration Control by Suppression (**Section 4.3.1.3**)
- Deflagration Control by Venting (**Section 4.3.1.4**)
- Deflagration Control by Containment (**Section 4.3.1.5**)

4.3.1.1 NFPA Guidance on Pre-deflagration Detection

Pre-deflagration detection systems are utilized when "…a specific ignition source has been identified as the most probable means of ignition [15, p. 51]." These detection systems are limited to detecting an identifiable ignition source. Detection systems can utilize several techniques based on the potential ignition sources, such as optical sensing systems and gas sensing systems.

The optical sensing systems, also called spark or ember detectors, detect radiant energy from a hot or glowing particle within the process equipment [55, p. 14]. Optical sensing systems can be used to trigger a subsequent mechanism to control or extinguish the hot or glowing material.

Gas detection systems detect gaseous products from the initial stages of a fire within the process [55, p. 14]. Gas sensing systems are installed in conjunction with a means to extinguish the initial fire, trigger alarms, and automate shutdowns.

Neither optical sensing systems nor gas detection systems can be used to extinguish or isolate a fire once it progresses to a deflagration flame front [55, p. 14]. These systems are intended to detect and mitigate incipient-stage fires and smoldering events.

The CSB requested documentation from Didion about the facility's dust explosion safety systems, including deflagration detection and prevention systems. The CSB found no evidence that Didion used such equipment throughout the facility.

Detection systems can trigger the activation of subsequent safeguards, including an emergency alarm system to notify employees of a potential upset condition. The detection system can also be tied in with other engineering controls to mitigate a detected ignition event further. The use of active engineering controls can trigger safety systems and prevent the reliance on employees to identify the location of a deflagration in its initial stages.

The CSB concludes that had Didion employed the use of optical or thermal detection safety systems within the ducting or process equipment, the initial ignition source could have been detected quicker and more accurately to allow the smolder fire to be addressed and could have prevented the incident.

4.3.1.2 NFPA Guidance on Deflagration Control by Isolation

Deflagration isolation is "a method employing equipment and procedures that interrupts the propagation of a deflagration flame front past a point (usually in a pipe) [12, p. 771]." Isolation is "a means of preventing certain stream properties from being conveyed past a predefined point [55, p. 8]." NFPA defines two isolation approaches, active and passive, to provide "interruption or mitigation of flame, deflagration pressures, pressure piling, and flame-jet ignition between enclosures interconnected by pipes or ducts [55, pp. 18, 22]."

Active isolation techniques incorporate detection, control, and an energy source independent of the process that activates an isolating barrier [55, p. 18]. Active isolation system design can be based on various techniques that include, but are not limited to, the use of the following equipment [55, p. 18]:

(1) Flame front extinguishing system (chemical isolation)
(2) Fast-acting mechanical valve (explosion isolation valves)
(3) Actuated float valve
(4) Actuated pinch valve

Passive isolation techniques create an isolating barrier independent of the detection of a hazard [55, p. 22]. Passive isolation system design can be based on various techniques that include, but are not limited to, the use of the following equipment [55, p. 22]:

(1) Flame front diverters
(2) Passive float valves
(3) Passive flap valves
(4) Material chokes (rotary valves or airlocks)
(5) Static dry flame arresters
(6) Hydraulic (liquid seal)–type flame arresters
(7) Liquid product flame arresters

Due to the interconnected nature throughout Didion's facility, the deflagration that occurred within the process was able to propagate throughout the equipment and dust collection systems. While isolation engineering controls cannot prevent a deflagration, these controls can prevent or limit the spread of the deflagration to subsequent equipment. Didion did not have active deflagration isolation systems within any of the vent systems that could prevent the propagation of a deflagration occurring within the system.

One potential passive isolation system in industry process that can be employed are rotary airlocks. While Didion utilized rotary airlocks, these valves did not meet the design and maintenance requirements of NFPA 69, chapter 12, and therefore could not prevent the propagation of the flame front within the process.

The CSB concludes that the lack of deflagration isolation engineering controls allowed the flame front to propagate from the initial fire location throughout the mill facility via the interconnected systems, contributing to the widespread damage in the mill.

4.3.1.3 NFPA Guidance on Deflagration Control by Suppression

Deflagration suppression systems, sometimes known as explosion suppression systems, prevent or mitigate explosions by detecting an explosion in its incipient stages and preventing the buildup of explosive pressure [4, p. 208] [13, p. 10]. Alternately, deflagration suppression can be described as "…a high-speed flame-extinguishing system that detects and extinguishes a deflagration before destructive pressures are created [15, p. 48]." **Figure 52** provides an example of a suppression system utilized within a process vessel.

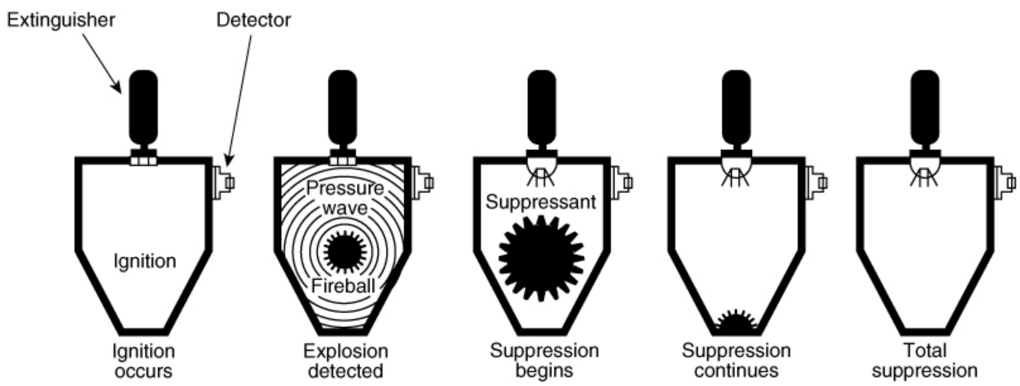

Figure 52: Deflagration suppression sequence. (Credit: NFPA [15, p. 49])

Deflagration suppression systems are active engineering controls, as they activate once the ignition is detected. Deflagration suppression systems are installed on mills, dust collectors, pneumatic conveyors, duct work, and dryers to protect the equipment from deflagrations. Deflagration suppression systems are limited in application, however. These limitations include the need to suppress the deflagration in the early stages of fire and pressure generation. Furthermore, suppression can be limited by the properties of the materials in the system and the design of equipment, which can inhibit the effectiveness of the suppressant [55].

While there can be concerns about water suppression in specific applications, such as food products, there are alternate means of suppression. Inert gases, such as carbon dioxide and nitrogen, can be used to sufficiently disrupt the ignition of a combustible material before a deflagration can travel to connected equipment. The use of inert gases can present a separate hazard of an oxygen-deficient atmosphere. Alternately, inert solids, such as sodium bicarbonate, can be used for deflagration suppression.

The CSB concludes that had Didion employed the use of deflagration suppression systems, in conjunction with isolation engineering controls, the initial deflagration event could have been limited to the equipment and ducting around the ignition site. Had the propagation been halted, the incident could have been mitigated and could have prevented the subsequent explosions, structural collapses, and injuries and fatalities.

4.3.1.4 NFPA Guidance on Deflagration Control by Venting

The NFPA defines a deflagration vent as "an opening in an enclosure to relieve the developing pressure from a deflagration [44, p. 9]." Deflagration venting operates by opening at a predetermined pressure, which allows the "…pressurized gases [to be] discharged to the atmosphere either directly or via a vent duct, resulting in a reduced deflagration pressure… below the rupture pressure of the process vessel or room [15, p. 47]."

Alternately, the CCPS defines deflagration venting as "the reduction of pressure generated in a vessel by a deflagration by allowing the emergency flow of the vessel contents from the vessel by means of an opening in the vessel, thus avoiding the failure of the vessel by overpressure [12, p. 774]."

Two types of main deflagration vents are deflagration vent panels and vent doors [15, p. 47]. A deflagration vent panel is a "flat or slightly domed panel that is bolted or otherwise attached to an opening on the process component to be protected. The panel can be made of any material and construction that allows the panel to either rupture, detach, or swing open from the protected volume [15, p. 47]." A deflagration vent door is "a hinged door mounted on the process component to be protected. It is designed to open at a predetermined pressure that is governed by a special latch arrangement [15, p. 47]." Deflagration venting can be applied to process equipment and buildings to relieve pressure from a dust explosion [15, p. 16].

4.3.1.4.1 Deflagration Venting Design

Didion used deflagration vents in portions of its process; however, not all equipment involved had designed venting protections. The CSB requested design documentation of the deflagration venting systems throughout the mill, but Didion provided no relevant documentation. The deflagration venting systems present at Didion were observed during inspections of the mill and equipment following the incident.

The Dry Grit Filter had deflagration venting installed on the filter housing. The deflagration vents did open as part of the incident when the pressure exceeded the opening pressure for the panels. In **Figure 53**, the Dry Grit Filter is shown with the opened deflagration vent panels and evidence that the deflagration damaged the exhaust ducting. Didion's deflagration venting systems were inadequate; despite the presence of these vents in conjunction with the lack of isolation controls, some equipment still ruptured from the overpressure.

Figure 53: Dry Grit Filter installation. Open vent panel is denoted by the orange circle, and the exhaust ducting damage is highlighted by the red circle. (Credit: CSB)

The CSB concludes that Didion did not have adequate deflagration venting systems to prevent equipment rupture that experienced overpressure, such as the South BM Cyclone and dust collector ducting. Had Didion properly implemented deflagration venting systems, some of the significant property damage could have been prevented, reducing the severity of the incident.

4.3.1.4.2 Venting to a Safe Location[a]

As discussed in the 1995 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, "Venting shall be directed to a safe, outside location away from platforms, means of egress, or other potentially occupied areas [56]." Furthermore, Chapter 6 of the 2018 edition of NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, states that the relief from an enclosure due to a deflagration shall minimize property damage and employee injuries.

> Property damage and injury to personnel due to material ejection during venting shall be minimized or avoided by locating vented equipment outside of buildings and away from normally occupied areas [44].

During a dust deflagration, unburned combustible dust can be ejected from the deflagration vents and introduced to the surrounding area, providing additional fuel that could generate a fireball. The 1998 edition of NFPA 68 discusses this phenomenon.

> Normally when dust deflagrations occur, there is far more dust present than there is oxidant to burn it completely. When venting takes place, large amounts of unburned dust are vented from the enclosure. Burning continues as the dust mixes with additional air from the surrounding atmosphere. Consequently, a very large and long fireball of burning dust develops that can extend downward as well as upward. Personnel enveloped by such a fireball are unlikely to survive. The potentially large size of the fireball that extends from the dust deflagration vent should be considered when locating vents and vent ducts [57].

While the Dry Grit Filter was located outside of the mill buildings, the deflagration venting from the filter housing presented a hazard to the facility structure and the employees. The pressure relief vents installed on the Dry Grit Filter discharged into an occupied area. During the incident, the deflagration vent doors opened and exposed an employee to the flame front and the pressure wave that was relieved from the equipment, injuring the employee. **Figure 54** shows the location of the Didion employee when the deflagration vents on the Dry Grit Filter opened. The employee suffered burns when he was enveloped by the relieving flame front.

[a] The CSB has investigated at least four incidents involving relief to unsafe locations; these incidents resulted in at least 19 fatalities and 207 injuries. [Hazards Posed by Discharges from Emergency Pressure-Relief Systems | CSB Safety Alert]

Figure 54: Approximate location of employee at the time of the Dry Grit Filter vent opening. (Credit: CSB)

Dating back to the 1995 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, the NFPA standard recommends that equipment with venting, such as air-material separators, should be located outside the buildings or have venting directed to a safe, outside location [56]. While not causal to the incident or its consequences, the cyclones on 4D also had unsafe deflagration vent locations. As shown in **Figure 55**, the 4D cyclones show at least three deflagration relief panels that are installed. These rupture disks were designed to directly vent into the D Mill building, which could potentially expose employees to relieving flame fronts. Further, because these relief panels were installed inside a building, should the rupture disks open, disturbances of any fugitive dust in the building could trigger secondary fires or explosions. Relieving the deflagration into the building also poses the hazard of destabilizing the structure and causing a collapse. While there was evidence of burn damage, the rupture disks did not appear to open during the incident. Rather, the rupture disks were likely damaged during building demolition and not overpressure.

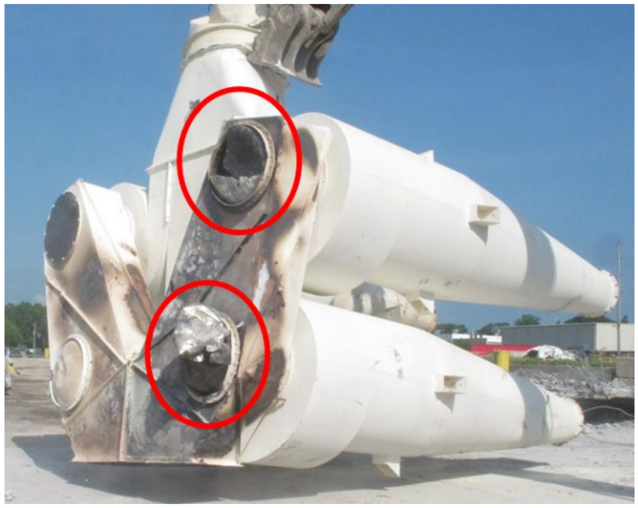

Figure 55: 4D Cyclones with rupture disks, with red circles indicating damaged rupture disks. (Credit: Didion, annotations by CSB)

The CSB concludes that a deflagration vent on the dust collection equipment opened during the incident and directed flames at an evacuating employee who sustained significant burn injuries. Had the vent been installed to prevent exposure to employees, as required by NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, the burn injury could have been prevented.

4.3.1.5 NFPA Guidance on Deflagration Control by Containment

The NFPA discusses deflagration control by pressure containment in NFPA 69, *Standard on Explosion Prevention Systems*. Pressure containment is "…the technique of specifying the design pressure of a vessel and its appurtenances so that they are capable of withstanding the maximum pressures resulting from an internal deflagration [12, p. 771]." Pressure containment incorporates inherently safer design principles to prevent the potential for the rupture of equipment. Pressure containment requires the system to be designed based upon test data of the maximum pressure generated by a deflagration [12, p. 315]. Deflagration containment cannot be used for interconnected vessels that are connected by large diameter piping or ducts unless additional requirements are undertaken to address the interconnection of the equipment. The requirements to address these limitations include [55]:

(1) Deflagration isolation is used on interconnected piping.
(2) Deflagration venting is used for interconnected piping.
(3) Interconnected vessels are designed to withstand increased pressure due to pressure piling.
(4) Isolation or venting is used in one of the interconnected vessels.

Based on photographic evidence, sections of ducting and the South BM Cyclone on 1B were subjected to excessive pressure, causing a number of ruptures, which likely released unburned combustible dust and fire, further fueling additional external fires and explosions. Didion did not design ducting and equipment to withstand the pressure generated by deflagrations. The ducting used within the mill was constructed of sheet metal or similar materials of construction and was not able to contain the pressures generated by deflagrations.

The photographic evidence shows the ducting experienced failures resulting in loss of containment at the inspection ports located on the Dry Grit Filter ducting on the roof of B Mill. The failure of the inspection ports acted as exhaust points to relieve pressure and redirect flames, as shown in **Figure 56**. The excessive pressure generated within the ducting caused some ducting joints to separate at the points of attachment.

Figure 56: Dry Grit Filter ducting with overpressure indications. (Credit: CSB)

The ducting immediately upstream of the Torit Filter shows significant pressure-related damage at the connections between ducting sections (**Figure 57**). The ducting flanges appear to have experienced significant internal pressure, causing the metal to separate and provide a relief path for the gases, flames, and unburned dust in the system.

Figure 57: Left: Torit Filter supply duct; right: Dry Grit Filter supply duct on roof of B Mill. (Credit: CSB)

The CSB concludes that Didion did not adequately design its dust collection system ducting to withstand deflagration pressures, nor did it provide adequate deflagration venting or isolation, resulting in the rupture of ducting, which allowed deflagrations to propagate outside of the process equipment.

4.3.2 OSHA Requirements for Deflagration Engineering Controls

The OSHA *Grain Handling Facilities Standard* requires deflagration engineering controls on dust collection systems. Filter dust collection systems must meet one of three scenarios. These requirements are:

- Dust collection systems should be located outside of the facility; or
- Located inside the facility but with an explosion suppression system; or
- Located inside the facility, separated by fire-resistant construction, located adjacent to an exterior wall, and vented to the outside. The vent and ductwork shall be designed to resist rupture due to deflagration [17, p. 7].

At the time of the incident, the Dry Grit Filter was located outside of the facility; however, several dust collectors, including the Torit Filter, were located inside the facility but did not vent outside of the building. Furthermore, these collectors were not equipped with suppression systems. When the flame front propagated to the Dry Grit Filter, the lack of deflagration suppression systems allowed subsequent explosions to occur within the Dry Grit Filter and propagate back into the facility, causing additional damage. Additionally, when the deflagration venting on the Dry Grit Filter did open, the flames were directed toward an occupied area, which engulfed an employee and caused significant burn injuries to the employee.

The CSB concludes that Didion did not provide explosion protection in accordance with the OSHA *Grain Handling Facilities Standard* by not installing venting that directed outside of the building or implementing explosion suppression systems on the dust collection systems. Had Didion installed explosion protections, as prescribed by the *Grain Handling Facilities Standard*, the severity of the incident could have been mitigated through the use of explosion suppression systems or deflagration venting.

OSHA cited Didion for lack of explosion protection on filter media dust collectors located within the facility.

4.3.3 Gaps in Regulatory Requirements

The OSHA *Grain Handling Facilities Standard* requires explosion protections for filter media dust collector systems based upon the location of the dust collection system. However, the *Grain Handling Facilities Standard* does not require controls for deflagrations with respect to pre-deflagration detection or deflagration isolation, which, had they been installed at Didion, could have helped prevent the escalation of the incident. Furthermore, as discussed above in **Sections 4.3.1** and **4.3.2**, the NFPA guidance provides more prescriptive requirements for the design and installation of engineering controls, such as deflagration venting, containment, and suppression.

The CSB concludes that the OSHA *Grain Handling Facilities Standard* does not adequately provide direction for the inclusion of engineering controls, such as deflagration detection, isolation, or containment, that could prevent the propagation of fire or explosions through process equipment. Had Didion been required to implement deflagration engineering controls, such as detection or isolation, the incident could have been limited to the initial fire and explosion but not allowed to propagate and cause more widespread damage and injuries to employees.

The CSB recommends that OSHA develop a Combustible Dust Standard that incorporates engineering requirements for deflagration controls to include deflagration detection, isolation, and containment, such as the requirements discussed in NFPA 69, *Standard on Explosion Prevention Systems*.

Furthermore, the OSHA *Grain Handling Facilities Standard* does not account for process equipment, such as cyclones or other air-material separators, when assessing for deflagration control. While dust collection systems, which are addressed in the *Grain Handling Facilities Standard*, can experience deflagrations, other equipment can also experience deflagrations, but these pieces of equipment are not addressed in the OSHA standard. The NFPA, for example, requires protection of all air-material separators, such as cyclones. Furthermore, the *Grain Handling Facilities Standard* does not provide any requirements for the siting of equipment, such as cyclones or other air-material separators, that could have deflagration venting that pose the same hazard as a dust collector during a deflagration venting event. As with the incident at Didion, many of the pieces of equipment involved in the fires and explosions were not covered under the *Grain Handling Facilities Standard*.

The CSB also concludes that the OSHA *Grain Handling Facilities Standard* does not address the deflagration venting requirements of air-material separators, such as cyclones, that could present the same hazard as dust collectors.

The CSB recommends that OSHA develop a Combustible Dust Standard to require deflagration controls for all pneumatic conveying and air-material separation equipment, such as those provided in NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, and NFPA 69, *Standard on Explosion Prevention Systems*. Furthermore, the CSB recommends that the siting of all equipment that includes deflagration venting should be included per NFPA 69, *Standard on Explosion Prevention Systems*.

4.4 Structural Design for Combustible Dust Hazards

During the incident, the pressure generated during the dust explosions throughout the facility resulted in the collapse of several buildings and significant damage to the remaining buildings. The collapse of the buildings directly resulted in serious and fatal injuries to Didion employees.

The CSB requested documentation, including plans, drawings, permits, and timelines for construction and modifications for each area of the mill facility. Didion provided structural drawings of the various buildings. A review of the drawings and design documentation did not show any design considerations for overpressure or indicate any deflagration venting to mitigate dust explosion hazards.

The CSB concludes that Didion either did not consider potential dust explosion hazards during the design and construction of the mill facility buildings or did not implement engineering controls for such hazards.

4.4.1 Guidance on Structural Design for Combustible Dust

4.4.1.1 FM Global Guidance on Damage-Limiting Construction

In 1992, FM Global first published a loss prevention data sheet, *Grain Storage and Milling*, which recommends that milling facilities be constructed using steel or reinforced concrete [58]. The FM Global property loss prevention data sheet 1-44, *Damage-Limiting Construction*, provides guidelines for the design and construction of building components for rooms or buildings where an explosion or deflagration hazard exists [58].

FM Global discusses several options for construction methods to limit damage during explosions. The *Grain Storage and Milling* guidance states that "all construction should be steel or reinforced concrete frame with explosion-relieving panels…" to mitigate damage. Pressure-relieving construction is intended to vent the force of an explosion to mitigate the damage from an explosion. Pressure-resistant construction provides means to "… absorb and resist the initial explosion force until it is vented by pressure-relieving walls." This type of construction includes reinforced concrete.

Didion's mill buildings were a mixture of various concrete construction methods.

Table 4 below summarizes the mill construction history with basic construction method. A Mill was mainly cast-in-place[a] concrete construction, while the remaining buildings were pre-cast concrete or tilt-up construction[b] with some poured floor or roof slabs.

Table 4: Didion dry corn mill facility construction timeline and method. (Credit: Didion)

Date Constructed	Mill Building	Construction
1991	A Mill	Cast-in-place concrete
1994	Boiler Room	Single story Pre-cast tilt-up walls with hollow core roof supported on steel anchored to the walls
1998	Multipurpose Building[c]	Pre-cast tilt-up with a hollow-core plank roof Hollow core horizontal slabs simply rested on pre-cast beams
2001-2002	B Mill	Cast-in-place floor slabs and columns Pre-cast wall panels
2004	F Mill	Pre-cast concrete walls with a combination of cast-in-place floor slabs and pre-cast floor slabs or planks
2010	C Mill	Pre-cast tilt-up construction like B Mill and F Mill Located within the Multipurpose Building
2011	D Mill	Pre-cast walls Perimeter pre-cast walls were continuous from the cast-in-place stem wall up to the underside of the 4th floor and contained additional panels at the 4th-floor slab up to the roof. Cast-in-place floor and roof slabs

[a] The Portland Cement Association defines *cast-in-place* concrete as, "made with ready-mix concrete placed into removable forms erected on site [90]."

[b] The Portland Cement Association defines panel systems for concrete construction, which include *pre-cast* and *tilt-up* concrete: "There are two main types of panel systems used for concrete walls: precast concrete and tilt-up concrete. Both types of panels are typically erected with a crane but differ in where they are cast. Precast concrete panels are built in a controlled manufacturing facility and shipped to the site on trucks. Tilt-up panels are site cast from ready-mixed concrete, usually formed on top of the floor slab, for minimal site disruption [91]."

[c] The Multipurpose Building housed several different functions and operations, including Warehouse, Quality Control Lab, Maintenance Shop, Administrative Offices, Packaging Operations, and C Mill.

As described in **Appendix D**, the support structures of F Mill, C Mill, and the Multipurpose Building were interconnected with B Mill wall and floor sections. As the mill was constructed to share the pre-existing walls during facility expansions, the mill's overall structural stability depended on the integrity of all the buildings in the mill together due to the interconnected nature of the walls in each building. The destabilization of a common wall between two buildings could result in the risk of collapse. As a result of the overpressure of the buildings caused by secondary dust explosions external to the process but internal to buildings, the interconnected structure began to lose structural stability, likely exacerbating the damage to the mill buildings. The initial explosions occurred on 1B. The B Mill walls were displaced laterally, destabilizing the walls and support members of the adjacent buildings, contributing to the building collapse of F Mill and the Multipurpose Building. Additionally, the Multipurpose Building roof was displaced, which also contributed to the collapse of the building. Furthermore, the lack of adequate pressure-resistant construction allowed the secondary explosions in A and B Mills to separate the walls from the 4B section of the mill.

Key Lesson

Companies should review fire and building codes to determine the type of construction and evaluate any additional requirements based on the hazards of the materials being handled in the process. Furthermore, companies should evaluate any additional mitigations or safeguards needed in their processes if existing buildings do not meet fire or building codes.

The CSB concludes that Didion did not design the mill buildings to withstand overpressure events, construct its mill buildings in accordance with industry guidance to mitigate the damage during a combustible dust explosion, or install deflagration venting on the mill buildings to relieve excessive pressure from secondary explosions. Had Didion constructed the buildings in accordance with this guidance, the extensive damage and collapse of mill buildings could have been prevented.

4.4.1.2 NFPA Guidance on Deflagration Venting from Structures

The NFPA discusses the requirements for deflagration controls that can be incorporated into the structural design of facilities. The NFPA 61 standard requires venting for building and infrastructure protection from deflagrations. The standard requires, "[i]f a dust explosion hazard exists in rooms, buildings, or other enclosures, such areas shall be provided with explosion relief venting [59, p. 7]." The 1997 version of NFPA 68, *Guide for Venting of Deflagrations*, discusses the need for deflagration venting to prevent structural damage to buildings that could experience deflagrations.

> Deflagration venting is provided for enclosures to minimize structural damage to the enclosure itself and to reduce the probability of damage to other structures. In the case of buildings, deflagration venting can prevent structural collapse [57].

The CSB requested structural and building design documentation, including any deflagration venting for the buildings in the mill facility. Didion provided structural drawings of the various buildings; however, Didion did not use deflagration venting on the buildings.

The CSB concludes that the lack of deflagration venting for the facility structures likely contributed to the building collapses due to the combustible dust explosions. Had Didion installed deflagration venting as

part of the building design, the building pressure could have been relieved, mitigating the damage to the buildings, and potentially preventing the collapse of the mill buildings.

4.4.2 Gaps in Regulatory Guidance For Structural Design

4.4.2.1 State of Wisconsin

Wisconsin adopted the International Building Code (IBC) as the state building code in 2001 [60]. Wisconsin did not adopt the International Fire Code (IFC), which contains requirements for combustible dust in Chapter 13, *Combustible Dust-Producing Operations*. At the time of the incident, Wisconsin required facilities to meet the requirements of the 2012 edition of NFPA 1, *Fire Code*. NFPA 1 further required implementation of other NFPA guidance, such as the 2008 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, and the 2007 edition of NFPA 68, *Standard on Explosion Protection by Deflagration Venting*.

The Wisconsin Administrative Code only adopted some sections of NFPA 1 but did not adopt requirements of the design standards. As such, the requirements governing the design of processes and buildings were not applicable. The Wisconsin Administrative Code states that "…design requirements in NFPA 1 and in any standard or code adopted therein that apply to… places of employment are not included…" and "this chapter does not prescribe how to design public buildings [61]."[a] Furthermore, the Wisconsin Administrative Code does not require any compliance with standards that were published after the adoption of the *Fire Code*, such as NFPA 652.

The CSB concludes that prior to the incident, the Wisconsin Administrative Code had not adopted requirements to mitigate combustible dust hazards, such as those prescribed by Chapter 13 of the International Fire Code. These requirements could have compelled Didion to implement a building design to mitigate the combustible dust explosion hazards present during the incident that resulted in building collapse and serious and fatal injuries to Didion employees.

In May 2018, following the incident at Didion, Wisconsin adopted portions of the 2015 editions of the IBC and IFC [62]. The sections adopted into the state building code included considerations for designing and constructing certain facilities, including combustible dust-producing operations.[b] One such adopted section is Chapter 22 of the IFC which covers the requirements for combustible dust handling facilities [25].

4.4.3 Post-Reconstruction Analysis

As part of the reconstruction effort, Didion hired an engineering firm to size and design structural relief panels in accordance with the 2013 edition of NFPA 68, *Standard on Explosion Protection by Deflagration Venting*. These panels were sized using various dust explosibility characteristics based on test data from Didion.

[a] SPS 314.01(2)(a)(1)
[b] SPS 361.03(14)

Didion based its design and reconstruction on as-received dust samples, including particle size and moisture content.[a] Didion did not test the material using the ASTM E1226 standard (**Section 4.1.1)**, which accounts for worst-case scenarios for combustibility of dust samples. As with the facility prior to the 2017 incident, the failure to account for worst-case scenarios could result in significant building damage if a dust explosion occurred.

The documents provided to the CSB by Didion showed multiple iterations of the calculations for the required venting areas based on the K_{St}, mass of dust cloud, depths of dust accumulations, and the percentage of the building areas covered in dust. Many of these calculations indicated that the vent areas installed were less than the available vent area. The preliminary calculations indicate the potential for inadequate deflagration venting. There was no documentation provided about the building design to determine the construction strength to withstand the pressure generated from an explosion.

The CSB concludes that following the 2017 incident, Didion assessed the combustible dust to incorporate into the structural design of the reconstructed facility. While Didion assessed the material for combustibility, Didion did not assess the dust for a worst-case scenario according to ASTM standards, which could result in building collapse and significant injuries. The lack of structural design considering worst-case combustible dust hazards would not prevent a re-occurrence of structural collapse like the failures during the 2017 incident.

The CSB recommends that Didion use a competent third party to assess and implement engineering controls for the structural design and venting requirements of the reconstructed facility to ensure they meet the NFPA 68 requirements and guidance for adequacy of venting capacity.

4.5 Fugitive Dust Management

On the night of the incident, secondary explosions accounted for significant building damage, collapse, and employee injuries, as discussed in **Section 3.2** and **Section 4.4**. Employees described a series of explosions, some of which were outside the process (**Section 2.3**). These secondary explosions were at least partly fueled by fugitive dust already present inside the mill buildings before the incident began (**Section 3.1.5**). This is why housekeeping[b] is important in facilities containing combustible dust; minimizing fuel available for secondary explosions is one of the most important ways to mitigate or prevent combustible dust explosions [6, pp. 38-39].

To be effective, housekeeping must be done consistently and leave no unmonitored areas for dust to accumulate. Conversely, a housekeeping program alone does not constitute a complete combustible dust safety program, as housekeeping alone does not mitigate against other types of combustible dust hazards such as the propagation(s) and process fire(s) in the Didion incident, as described in **Section 4.3**.

Procedures are a type of administrative control in the hierarchy of controls (as discussed in **Section 1.4**) put in place to protect employees from hazards. An administrative control typically includes both a written program and activities driven by the written program [63, pp. 144-145]. Housekeeping, in the context of combustible dust

[a] The dust explosibility testing was performed following the incident as part of the reconstruction effort. The data from the dust testing were not provided to the CSB. The only information provided to the CSB were design specifications for the deflagration venting.

[b] For the purposes of this report, “housekeeping” is synonymous with fugitive dust control or fugitive dust management. Didion and NFPA standards both use “housekeeping” when describing fugitive dust control or management [6, pp. 23-24].

hazard management, pertains to procedures and activities to reduce fugitive dust accumulation on ledges, floors, equipment, and other indoor surfaces [23, p. 14]. Housekeeping is critical to preventing significant secondary combustible dust explosions because successful housekeeping minimizes fugitive dust in the first place [31, p. 297].

4.5.1 Didion's Fugitive Dust Management Practices

Master Sanitation Program

Didion's housekeeping program was the site's sanitation program. The sanitation program was structured with a parent procedure, known as the Master Sanitation Program. The Master Sanitation Program governed additional procedures, among them the Master Sanitation Schedule and the Monthly Sanitation Inspections. The Master Sanitation Program's purpose was "to define the processes used for cleaning the mill facility and equipment to ensure food safety."

The Master Sanitation Program directed employees to clean the facility and equipment according to the Master Sanitation Schedule. The Master Sanitation Program also relied on a risk analysis, the Hazard Analysis and Critical Control Points[a] (HACCP), to identify equipment cleaning schedules in the Master Sanitation Schedule.

In interviews, several Didion employees reported that in addition to food safety, Didion also used the Master Sanitation Program as the combustible dust hazard control program. However, the only mention of combustible dust in the Master Sanitation Program was:

> OSHA requires priority cleaning of fugitive grain dust accumulations whenever they exceed 1/8 inch at priority housekeeping areas, including but not limited to boots of elevators, floor areas within 35 feet of inside elevators, floors of enclosed areas containing grinding equipment, and floors of areas containing grain dryers located inside the facility.[b]

Master Sanitation Schedule

Didion's Master Sanitation Schedule served as the basis for completing cleaning activities for the mill facility. The Master Sanitation Schedule included checklists organized by cleaning frequency: semi-daily, daily, semi-weekly, weekly, semi-monthly, monthly, quarterly, and semi-annually. Within each frequency-based checklist, the Master Sanitation Schedule outlined physical areas and cleaning tasks required per the sanitation schedule. It also identified specific cleaning tasks as either a priority housekeeping item or a cleaning requirement per the HACCP, or both.

The areas listed in the Master Sanitation Schedule were focused on food safety hazards. The Master Sanitation Schedule did not mention areas that could harbor combustible dust hazards but were not perceived as a food safety concern. The dust collector ductwork systems were examples of this. Neither the dust collectors nor their

[a] HACCP plans evaluate facilities for biological, chemical, and physical hazards to food safety, and serve as the risk assessment which forms the basis for a facility sanitation program [64].

[b] Although Didion's Master Sanitation Program presented the requirement above as an OSHA requirement, a 1998 OSHA Interpretation Letter indicated that this requirement only applied to grain elevators, not dry corn mills. Difference between "grain elevators" and "grain handling facilities" | Occupational Safety and Health Administration (osha.gov)

Key Lesson

Companies should ensure that the standards applied are applicable and appropriate to the hazards inside the facility. Food safety standards, for example, are appropriate for preventing food hazards such as pathogens and contaminants from reaching consumers, but they are not intended to address workplace or process hazards such as combustible dust. Appropriate tools such as a DHA should be used to address process hazards like combustible dust.

associated ductwork was listed in the Master Sanitation Schedule. Another example was the air makeup shafts in A Mill and B Mill. Although both air makeup shafts were listed on the first-floor weekly checklists (in 1A and 1B), none of the other checklists mentioned them. The CSB found no evidence in either maintenance records or the Master Sanitation Schedule that areas adjacent to the process but not in direct contact with it were part of the housekeeping plan, including the A and B Mill air makeup shafts, hallways, stairwells, electrical rooms, or heating and ventilation ductwork. As discussed in **Section 3.2**, the extensive damage through the air makeup shafts and on 4A, for example, indicated that significant combustible dust accumulations were likely present on the night of the incident. As noted in **Section 2.3**, Employee A received severe burns while standing in a hallway near the B Mill stairwell and the control room entrance.

The CSB concludes that Didion's Master Sanitation Schedule did not adequately identify or require maintenance of all areas at the facility to minimize the hazard of fugitive combustible dust accumulations.

Hazard Analysis and Critical Control Points

Didion provided its HACCP plan to the CSB. The HACCP plan is required by both the United States Department of Agriculture (USDA) and the Food and Drug Administration (FDA) to ensure food and drug safety [64]. A HACCP plan evaluates the facility for biological, chemical, and physical hazards to food safety, and serves as the risk assessment that forms the basis for a facility sanitation program [64]. The FDA guidelines also describe the purpose of HACCP as "an effective and rational means of assuring food safety from harvest to consumption [64, p. 2]." The FDA HACCP guidance does not address combustible dust.

Although Didion provided its HACCP analysis to the CSB, Didion was unable to produce a risk analysis for combustible dust hazard management specifically. Didion's Master Sanitation Program specified that "HACCP analysis served as the basis for identifying equipment cleaning to be included on the Master Sanitation Schedule." Didion employees stated that they also used the Master Sanitation Program, including the HACCP, as their combustible dust hazard management program. However, Didion's HACCP did not contain any analyses of combustible dust hazards or scenarios. The HACCP only mentioned dust twice: once to state that a particular process step involved "removal of dust particulates plantwide, not a part of the food production process flow," and secondly to list "dust explosion" in the Emergency Risk Assessment. Additionally, although the "dust explosion" listing named control measures for a dust explosion emergency, no further analysis of this or any other combustible dust hazards was included in the HACCP. Equipment outside the food product flow, such as the Torit Filter, either was listed as "out of the food process" with no further evaluation, or not listed in the HACCP at all, such as the Dry Grit Filter. The Torit Filter ductwork and the Dry Grit Filter were directly involved in the incident, as described in **Section 3.1**.

The CSB concludes that Didion's purported use of the HACCP plan for identifying and mitigating combustible dust hazards was ineffective, as food safety programs are not intended to evaluate worker or process safety.

The CSB recommends that Didion develop and conduct combustible dust hazard analyses separately from the HACCP.

Monthly Sanitation Inspection

Didion performed monthly sanitation inspections to audit performance against the Master Sanitation Schedule. Didion maintained a Monthly Sanitation Inspection procedure and used forms to perform and document these performance audits. The Monthly Sanitation Inspection served to validate the cleanliness status of the facility through visual inspections. The Monthly Sanitation Inspection required at least one auditor from the Quality Assurance department and specified that auditors "will inspect the mill [facility] environment identifying and recording all sanitation and safety issues."

Didion provided to the CSB completed Monthly Sanitation Inspection forms dated January 2016 through April 2017, the month before the incident. Of the 16 months of data provided, all but two monthly inspection reports indicated heavy dust accumulation in 1B, and all were identified as a "medium" risk. In the cleaning procedure, Didion defined heavy accumulations on equipment as "more than NFPA/OSHA dust layer thickness limits (>1/8")" or "more than a moderate dusting" on walls. Employees performing the inspections did not appear to have a clear understanding for dust accumulation risk in the Monthly Sanitation Inspections. One manager who performed the monthly inspections believed that reduced insect evidence was also evidence of reduced combustible dust risk, stating, "…the insects are my biggest proof that it wasn't that bad on May 31st, because there were barely any insects anywhere."

Several dusty areas were identified in the Monthly Sanitation Inspection forms provided by Didion, including Bulk Loadout, 3F, 4B, Pack, 1B, and 1A (**Figure 8**), among others. Considering dust findings only, these areas consistently included findings of "heavy dust on floor" or actions to "blow down equipment and walls." As shown in **Table 5**, these areas had multiple dust-related audit findings of "heavy dust," "dust accumulation," or actions to "blow down" equipment or building areas nearly every month for the 16 months leading up to the incident. Each finding in **Table 5** represents a dust accumulation issue only; other food safety audit findings unrelated to dust are not shown. The areas listed in **Table 5** are not comparable to each other in terms of square footage or dust hazard severity. **Table 5** shows that despite consistent heavy dust findings and cleaning needs in several areas, Didion made no adjustment to the inspection or cleaning schedules in the 16 months leading up to the incident.

Table 5: Number of "heavy dust," "dust accumulation," or "blow down" Monthly Sanitation Inspection findings by area, January 2016 through April 2017. (Credit: CSB, data provided by Didion)

Monthly Inspection	Bulk Loadout	3F	4B	Pack	1B	1A
Monthly averages for 2016	4.7	3.2	2.9	2.5	2.4	2.4
Jan-17	4	4	3	3	4	4
Feb-17	5	4	4	3	3	3
Mar-17	7	3	3	3	2	3
Apr-17[a]	6	3	3	3	3	2
Total findings 2016-May 2017[b]	74	49	39	39	38	36

All of the areas noted in **Table 5** sustained severe damage in the incident. For example, the 3F area inspection indicated "heavy dust" or "product accumulation" in 15 of the 16 months prior to the incident. The F Mill building completely collapsed in the incident. Another example is the air shafts in A and B Mills. These shafts were listed in the Master Sanitation Schedule in 1A and 1B areas on the weekly checklist, and the 1B air makeup shaft was listed as a priority housekeeping area. Nevertheless, there was no evidence that Didion completely cleaned the airshafts weekly since they were not mentioned on any other floors. While the Monthly Sanitation Inspection was performed as a "walkaround" without any specific checklist for the auditor to follow beyond the Master Sanitation Schedule itself, findings of "product accumulation in air make-up shaft" were listed in the Monthly Sanitation Inspection forms 12 times in 16 months. The B Mill air shaft in particular had such a finding in each of the last five inspections prior to the incident. Moreover, the auditors who performed Monthly Sanitation Inspections did not receive any additional combustible dust training beyond that given to all employees at the mill facility.

Fugitive combustible dust is sometimes the result of process leaks, process plugging, cleanout, or other process upsets. Because of the lightweight and already-dispersed nature of dust capable of leaking from the process, fugitive dust may settle on any horizontal surface (and sometimes rough vertical surfaces) [11, p. 20]. **Figure 58** shows examples of fugitive dust accumulations at Didion in the weeks and months preceding the incident, as well as a dust accumulation identified the morning of the incident. The necessary cleaning and auditing frequencies to prevent fugitive dust accumulations should have been more frequent, given the findings of "heavy dust," "dust accumulation," or actions to "blow down" equipment or building areas in consecutive months (**Table 5**).

[a] The April 2017 Monthly Sanitation Inspection was actually performed on May 3, 2017. At the time of the incident (11 pm on May 31, 2017), the May 2017 inspection had not yet been performed.

[b] This is a total of the actual number of dust accumulation findings in each area from January 2016 through April 2017.

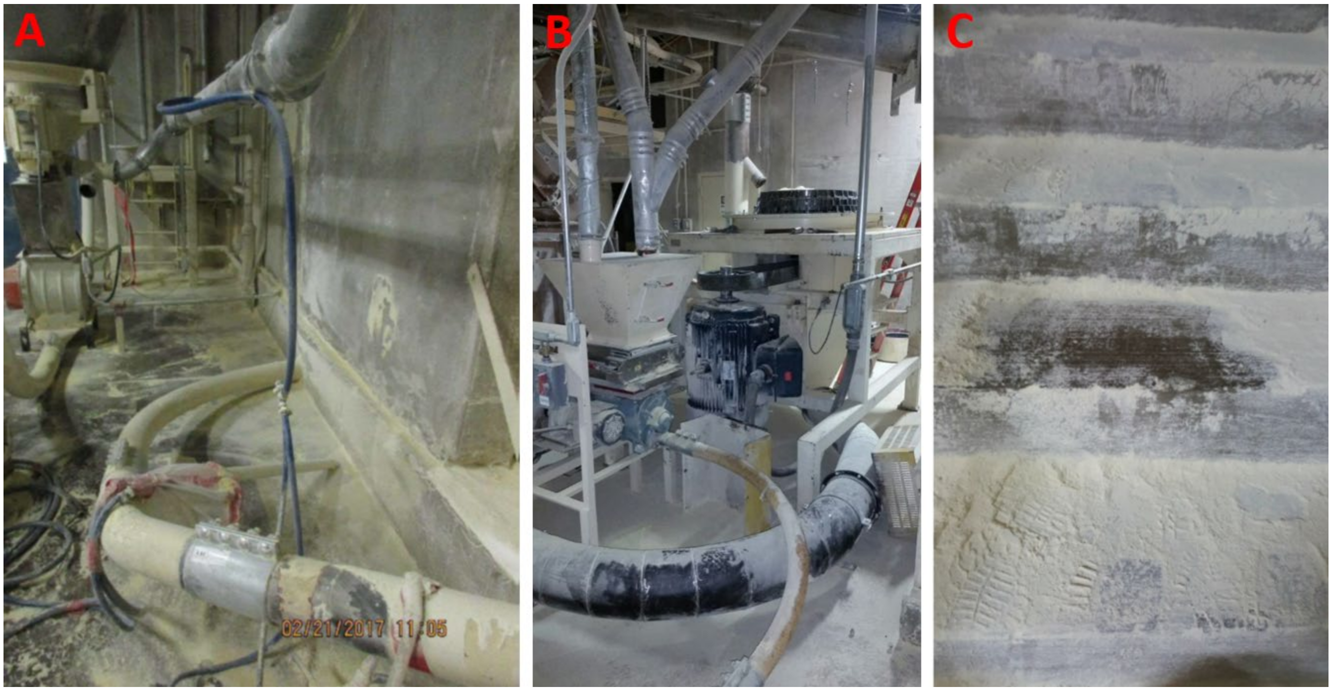

Figure 58: Examples of fugitive dust accumulations, (A) approximately three months before the incident, (B) approximately two weeks before the incident, and (C) less than 24 hours before the incident. (Credit: Didion)

If housekeeping was not effective enough to remove the accumulated dust or if acceptable cleanliness was too difficult to maintain, Didion could have put more effort into preventing dust accumulation in the first place, such as ensuring equipment was leak tight or using more welded transfer piping with fewer connections, and therefore fewer leak points. The CSB found no evidence that Didion considered these approaches, however. When multiple findings of dust accumulations occurred multiple months in a row, Didion should have implemented engineering controls higher up in the Hierarchy of Controls (**Section 1.4**), which would have been more effective than the administrative controls of housekeeping alone.

The CSB concludes that Didion's Monthly Sanitation Inspection had ineffective housekeeping practices to fully address fugitive combustible dust hazards and allowed unacceptable levels of combustible dust to accumulate in some areas without triggering action either to prevent combustible dust accumulation through leak prevention or altering the cleaning schedule to clean more frequently, contributing to the severity of this incident. As a result, secondary dust explosions fueled by fugitive dust led to building collapse and multiple injuries and fatalities.

The CSB recommends that Didion develop and implement a separate fugitive dust management program to identify and mitigate fugitive dust accumulation hazards. At a minimum, the program should include housekeeping and periodic inspections for hidden, overhead, or limited access areas that can harbor combustible dust accumulations.

4.5.2 Fugitive Dust Management Guidance

While Didion was required to comply with OSHA's *Grain Handling Facilities Standard*, Didion was not required to follow industry guidance for controlling fugitive dust. Industry and insurance groups have issued guidance that companies can voluntarily adopt to manage combustible dust risks in general and fugitive dust risks in particular. Among these are the CCPS within the American Institute of Chemical Engineers (AIChE) and NFPA.

The CCPS addresses fugitive dust prevention and protection in its *Guidelines for Combustible Dust Hazard Analysis*, which outlines a three-pronged approach to prevent dust layers: contain, capture, and clean [8, pp. 49-50]. Methods to accomplish the first two steps, contain and capture, include:

- Design and maintain equipment to minimize dust emissions. For example, run under a slight vacuum, and replace gaskets on a regular basis.
- Identify potential release points and provide a means to collect the release using vacuum pickups, such as elephant trunks or capture hoods. Typical operations that can be release locations include grinding, buffing, container dumping and filling, screening, filling of open bins, and open transfer points in conveying systems.
- Design the process room/building to limit the extent of dust migration. If possible, isolate the combustible dust areas from less hazardous areas and dissimilar hazardous areas. Refer to the discussion of separation, segregation, and detachment provided in NFPA 654, Section 6.2.
- Design the process room/building to minimize the amount of horizontal surfaces. FM Global Data Sheet 7-76, Prevention and mitigation of combustible dust hazards (FNG 2013) recommends installing 60-degree sloped covering over horizontal ledges.

Regarding cleaning schedules, CCPS advises:

> The final layer of defense in dust control is cleaning. When a facility defines an acceptable dust accumulation criterion, a cleaning schedule should be defined based on being able to ensure the dust accumulation levels in the plant do not exceed that criterion. Personnel should be trained to know when cleaning is required, even if prior to the scheduled cleaning time.

NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities* (2017 and 2020 Editions), contains guidance and requirements for combustible dust housekeeping:

- Dust on floors, structural members, and other surfaces shall be removed concurrently with operations.
- The facility shall develop and implement a written housekeeping program that establishes the frequency and method(s) determined best to reduce accumulations of fugitive agricultural dust on ledges, floors, equipment, and other inside exposed surfaces. Unless a greater threshold for housekeeping dust accumulation is prescribed in writing and justified by a documented risk assessment, the threshold housekeeping dust accumulation limit shall be 3.2 mm (1⁄8 in.) over 5 percent of the footprint area.
- Provisions for unscheduled housekeeping shall include specific requirements establishing time to clean local dust spills or transient releases [6, p. 23] [23, p. 14].

- A relatively small initial dust deflagration can disturb and suspend in air dust that has been allowed to accumulate on the horizontal and vertical surfaces of a building or equipment. This dust cloud provides fuel for the secondary deflagration, which can cause damage. The reduction of significant additional dust accumulations is, therefore, a major factor in reducing the hazard in areas where a dust hazard can exist [6, p. 43] [23, p. 43].

At the time of the incident, NFPA 61 (2017 edition) identified several necessary housekeeping measures, which Didion's Master Sanitation Program did not include. Among these were:

- Although Didion's housekeeping program did cover equipment and floors, it did not reliably or consistently cover structural members or "other surfaces," such as inside the air shafts for A Mill and B Mill.
- Because Didion did not establish a greater threshold, the threshold housekeeping dust accumulation limit was 1/8- inch "over 5 percent of the footprint area" of each room in the mill facility according to NFPA 61. The 1/8-inch limit was well understood by employees and well documented in Didion's procedures, but Didion did not specify an area over which this dust layer was acceptable. In large rooms, the difference between 5% and 100% of a room's area could be a significant quantity of fuel available to fuel secondary explosions.
- Didion's housekeeping protocols did not provide for unscheduled housekeeping and did not include specific requirements establishing time to clean local dust spills or transient releases.

The CSB concludes that had Didion implemented an effective fugitive combustible dust management program in accordance with NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, guidance, it could have reduced the severity of or eliminated secondary explosions.

The CSB recommends that Didion include in its combustible dust management program housekeeping practices in accordance with guidance contained in consensus standards such as Chapter 8.4 and Annex A of the 2017 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*. The program should include, at a minimum: a specific cleaning threshold such as a 1/8-inch dust layer, provisions for cleaning hidden and overhead surfaces that could harbor dust accumulations inside buildings, maximum surface area(s) that may be covered for each room, and provisions for unscheduled housekeeping, including specific time to clean local dust spills or transient releases.

4.5.3 OSHA Grain Handling Facilities Standard

OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272(j), addresses housekeeping requirements, in part by the following: [17, pp. 6-7]

> The employer shall develop and implement a written housekeeping program that establishes the frequency and method(s) determined best to reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces.

OSHA further defines additional requirements for grain elevators:

- Priority housekeeping areas shall include at least the following:
    - Floor areas within 35 feet (10.7 m) of inside bucket elevators
    - Floors of enclosed areas containing grinding equipment
    - Floors of enclosed areas containing grain dryers located inside the facility
- The employer shall immediately remove any fugitive grain dust accumulations whenever they exceed ⅛ inch (.32 cm) at priority housekeeping areas, pursuant to the housekeeping program, or shall demonstrate and assure, through the development and implementation of the housekeeping program, that equivalent protection is provided.
- Grain and product spills shall not be considered fugitive grain dust accumulations. However, the housekeeping program shall address the procedures for removing such spills from the work area.

Following the incident, OSHA cited Didion for several violations of the Housekeeping section of the *Grain Handling Facilities Standard*, 29 CFR § 1910.272(j), including: [17, pp. 6-7]

- Frequencies of housekeeping in the written programs "did not best reduce accumulations of fugitive dust emissions that are allowed to accumulate on elevated surfaces" of several buildings.
- Deficiencies in housekeeping methods, including "lack of specific cleaning methods or training on cleaning methods; compressed air usage as a cleaning method is tolerated; methods of accessing and cleaning overhead areas are not provided; lack of management oversight and verification of housekeeping; and fugitive dust emissions from numerous pieces of process equipment and transfer points are not accounted for where they are a source for dust accumulation."

These OSHA citations noted violations in areas 1A, 1B, 4B, and 3F.

Didion had a written housekeeping program in the Master Sanitation Program, but it did not specify methods. Although OSHA's *Grain Handling Facilities Standard* requires housekeeping, regarding cleaning methods it only states: "The use of compressed air to blow dust from ledges, walls, and other areas shall only be permitted when all machinery that presents an ignition source in the area is shut down, and all other known potential ignition sources in the area are removed or controlled." Much more extensive cleaning methods guidance is available in NFPA 61 as noted above in **Section 4.5.2**, but this guidance is not incorporated into the *Grain Handling Facilities Standard*. OSHA's standard only required Didion to have a written housekeeping program, and did *not* require Didion to do several items listed in NFPA 61, such as:

- Maintain a dust threshold level, such as 1/8-inch accumulated dust, at which cleaning was required;
- Apply the threshold over a limited area, such as 5% of the footprint area;
- Remove dust accumulations concurrently with operations;
- Address local dust spill or transient releases in a timely manner; or
- Provide for unscheduled housekeeping.

Didion's Master Sanitation Program mentioned that OSHA required priority cleaning of fugitive dust accumulations in priority housekeeping areas. Didion did identify these priority housekeeping areas in the Master Sanitation Schedule, although these requirements did not apply to dry corn mills, only grain elevators. The OSHA *Grain Handling Facilities Standard* identifies floors as priority areas, but it does not address other fugitive dust accumulation areas such as overhead or hidden areas. In 2003, the CSB investigated an incident at West Pharmaceutical Services in Kinston, North Carolina. This incident killed six workers and injured 38 others. In its 2004 report, the CSB determined that accumulated polyethylene dust above a suspended ceiling fueled the explosion [65, p. 11]. Similarly, the Didion incident included fugitive combustible dust accumulation in the air makeup shafts in A and B Mills and other areas not included in Didion's HACCP plan or Master Sanitation Schedule.

The CSB concludes that OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not include effective combustible dust housekeeping guidance included in current NFPA combustible dust standards, such as maintaining a dust cleaning threshold level, applying the threshold over a limited area, removing dust concurrently with operations, addressing local spills or transient releases promptly, providing for unscheduled housekeeping, or emphasis on cleaning overhead or hidden areas. This guidance could have strengthened Didion's fugitive dust management program, potentially reducing the severity or preventing secondary explosions.

OSHA's *Grain Handling Facilities Standard* unfortunately also states that "grain and product spills shall not be considered fugitive grain dust accumulations. However, the housekeeping program shall address the procedures for removing such spills from the work area [17, p. 6]." The hazard severity presented by spills can vary widely, depending on the grain handling facility in question. In a dry corn mill, particularly with product that has been milled to a small particle size such as bran (well below 425 microns), a spill can present a serious hazard, no different from a fugitive dust accumulation. Yet these situations are treated differently in the *Grain Handling Facilities Standard* in terms of timely response, even though the standard applies to a wide variety of grain handling facilities, including:

- marine terminal facilities,
- feed mills,
- flour mills,
- rice mills,
- dust pelletizing plants,
- dry corn mills,
- soybean flaking operations, and
- the dry grinding operations of soycake [17, p. 1].

Further, NFPA 61 requires that the threshold housekeeping dust accumulation limit is 1/8-inch "over 5 percent of the footprint area" of each room in a facility containing combustible dust. The *Grain Handling Facilities Standard* does not specify an area over which a dust layer is acceptable, and only applies the 1/8-inch dust layer threshold criterion to grain elevators. Because the OSHA standard includes no area limitation, it is thus permissible, for example, to allow 100% of a room's surface to be covered in a thickness of dust less than 1/8-inch in grain elevators, and any thickness in other facilities. In large rooms, this could result in a significant quantity of fuel available for secondary explosions. Some dry corn mills, such as Didion, have demonstrated that there is sufficient combustible dust to present a hazard, even at facilities other than grain elevators.

The CSB concludes that OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not adequately regulate combustible dust hazards. Deficiencies include:

a. **Only requiring grain elevators to maintain a maximum dust layer of 1/8-inch but not applying this standard to any other grain-handling facilities;**
b. **Designating priority areas that do not include areas known to have caused significant explosions in the past, such as hidden or overhead areas like suspended ceilings or the air shafts at Didion;**
c. **Allowing product spills to be treated differently from fugitive dust accumulations regardless of the hazard these spills might present; and**
d. **Allowing a dust layer over 100% of a room's area, rather than restricting allowable accumulation areas to a smaller size.**

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates housekeeping requirements, such as those in NFPA 61, for facilities that handle quantities of combustible dust, not grain elevators only. Requirements should include, at minimum:

a. **A specific cleaning threshold such as a 1/8-inch dust layer;**
b. **Provisions for cleaning hidden and overhead surfaces that could harbor dust accumulations inside buildings;**
c. **Maximum surface area(s) covered for each room that would trigger cleaning;**
d. **Provisions for unscheduled housekeeping, including time to clean local dust spills or transient releases; and**
e. **Provisions for treating combustible dust product spills as similar hazards to fugitive dust accumulations.**

4.6 Management of Change

Management of change (MOC) "is a process for evaluating and controlling modifications to facility design, operation, organization, or activities – *prior to implementation* – to make certain that no new hazards are introduced and that the risk of existing hazards to employees, the public, or the environment is not unknowingly increased [66, p. 1]."

4.6.1 Temporary Change to Bran System Flow

On May 3, 2017, approximately four weeks before the incident, a mill employee submitted change request documentation for approval to modify the Bran process "to hook up North Bauermeister blower line after cyclone airlock to South Bauermeister cyclone airlock to use both [B]auermeisters for bran production." This is the change shown above in **Section 2.2.4**. The request was a temporary change to test the modifications and was set to expire June 1, 2017, an hour after the incident occurred.

The change was implemented and reversed four times throughout May 2017, and Didion successfully operated the Bran system using the changed equipment configuration for several days in each case. The change was implemented for a fifth time at approximately 11:00 a.m. on May 31, 2017, the day shift preceding the incident. According to shift logs, the day shift crew transitioned out of producing material on the North BM at that time. When it was not producing its usual product, the North BM was available to switch over to Bran production using this temporary change.

On the night of the incident, the two receiving cyclones downstream of the North BM and South BM were connected together such that both were sharing a transport blower and transfer line to a single receiving cyclone on 4B that fed the Six-Section Sifter. **Figure 59** below shows the equipment configuration change.

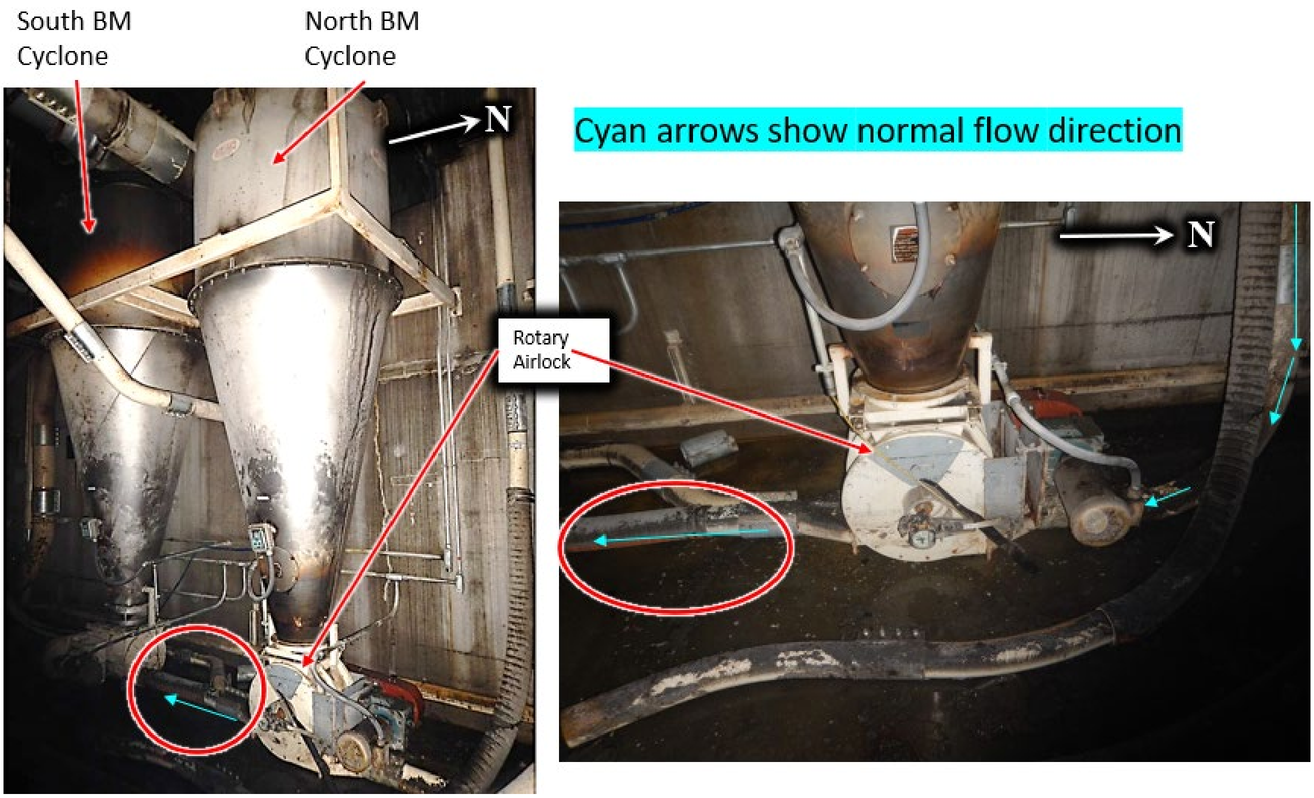

Figure 59: North and South BM receiving cyclones connected by rubber hose (circled). Cyan arrows show process/air flow. (Credit: CSB)

This configuration created a situation that used a single conveying air blower, but with a higher product flow demand on the transport line to 4B. Rather than each cyclone having a dedicated transport blower and line from 1B to 4B as was their original design, in this temporary configuration both BM Cyclones shared a single blower and line to move product from 1B to the Six-Section Sifter on 4B. This meant that a single blower and the same air volume was transporting more product than before the change was implemented. The temporary change documentation did not mention either this consequence, or the higher risk of product plugging the transfer line, backing up into the cyclones, or disrupting the airflow pattern inside the cyclones in this scenario. As discussed above in **Section 4.1.5**, Didion should have evaluated the impact this change could have on transport velocity, or whether sufficient transport air flow was available with a single blower to move the excess material to 4B in the change documentation before approving or implementing the change. No calculations were provided in the change documentation. The MOC documentation contained no statements that indicated what the higher loading on the pneumatic transport line was, by how much Bran system production rates could be safely increased, or what the minimum air velocity should be. The change documentation did not mention any effect on or changes to combustible dust hazards, dust collectors, transport velocities in pneumatic conveying, or potential plugging in the process due to higher process flow rates.

The CSB concludes that Didion did not adequately assess the temporary change of using a single blower system to transport material from two cyclones and the consequences of increasing solid material loading on the Bran process. Increasing solid material loading without increasing transport air flow can produce deposits, which created a situation favorable to harboring a smoldering nest downstream of the South BM.

During the incident, while Employees A and B were searching for the smolder source before the explosion, they did not search for a possible source around the North BM receiving cyclone on 1B or consider that the transfer system between the gap mills and 4B might be more prone to plugging due to the added product loading. The temporary change connecting the two systems had been made several times in May 2017, but this shift crew had likely never been involved in switching to or from the new configuration, based on when the switches were made and the shift crew's work schedule. There is no evidence that any of the Operators on the shift that night were aware of the change; one of the Operators specifically inspected the South BM receiving cyclone sight glass but did not investigate any other equipment involved in this change outside of the bottom of the South cyclone. Another was unsure whether the North BM was in operation at the time. The CSB found no evidence that the change was communicated to the affected Operators. The shift crew working on the night of the incident was not scheduled to be on site when any transition into or out of the change occurred, and the change was not mentioned in shift logs in at least the week leading up to the incident.

The CSB concludes that the temporary change made the day of the incident that connected the two gap mills' transfer systems together likely contributed to the incident in part by confounding the operators' search for the smoldering material when they were unaware the two mills' discharges were tied together.

4.6.2 Management of Change Process at Didion

Didion had an MOC[a] system in effect at the time of the incident "to ensure that changes to equipment, process technology, chemicals, or facilities do not introduce additional or unforeseen hazards." The program dated back to at least 2013 and consisted of an electronic MOC form and a written procedure. The procedure described the purpose and scope; defined key terms, roles, and responsibilities in completing an MOC; and outlined the process steps for completing an MOC, including for temporary and emergency changes. The procedure also gave examples of replacements in kind and changes that required the MOC process in several categories: procedures, equipment, electrical equipment, maintenance jobs, process technology, and chemical and facility changes.[b]

In the mill facility, MOC was a part of the HACCP process (**Section 4.5.1**). The MOC form contained questions and checklists for food safety and product quality: 18 fields dealt with food safety and quality, and 23 questions covered all other topics. **Figure 60** shows a portion of the MOC form including some of the process safety, food safety, and quality checklist questions on the form.

[a] "Management of Change" is historically a process safety term. "Change Management" is a term originating in HACCP for food safety concerns. Didion used "Change Management" to refer to any change, regardless of food safety or process safety concerns. In this report, the terms are considered synonymous, but for report consistency, "Management of Change" will be used throughout.

[b] The procedure specifically applied to both Cambria, Wisconsin facilities of Didion Milling and Didion Ethanol. Didion Ethanol was the name of Didion Bioscience at the time of the incident. It refers to the ethanol plant across the road from the Cambria mill facility.

PRESSURE RELIEF	
Introduce or alter any potential source of over/under pressure (or raise or lower temp)	No
Introduce a risk of increasing vacuum or pressure in any part of the system	No
Install any block valves that could isolate equipment from existing relief device(s)	No
In any affect the relief capacity available or required?	No
Installing or removing any relief devices?	No

EQUIPMENT & INSTRUMENTATION	
Alter the classification rating of any piece of equipment?	No
Install, replace, or remove any electrical equipment?	No
Instrument recalibration required?	Yes
Interlocks or alarms deactivated?	Yes
Alter control logic or tuning parameters?	No
Install, replace or remove any instrumentation?	Yes

SAFETY AND HEALTH	
Require additional safety equipment? (safety showers, fire extinguishers, gas detectors)	No
Affect any existing safety equipment?	No
Introduce new chemicals?	No
Introduce any new exposure potential?	No
Is there an impact on noise level?	Yes

MECHANICAL INTEGRITY INSPECTION PROGRAM	
Modify, eliminate, replace or add any equipment in an operating area falling under this Program?	Yes

Food Safety	
Management Representative responsible for this section	
Is the System Impacted?	No
Describe the Impact	N/A
Is this a Food Safety Team Agenda Topic?	N/A
Changes to the HACCP Plan?	N/A
Changes to the HACCP Process Flow and Hazard Analysis?	N/A
Sanitation concerns that would require an addition to the MSS?	N/A
Foreign material hazards?	N/A
Allergen concerns?	N/A
Microbiological concerns?	N/A

Quality	
Management Representative responsible for this section	
Is the System Impacted?	No
Describe the Impact	N/A

Figure 60: Excerpt of an example MOC form. Note safety questions on the left side; food and quality on the right. (Credit: Didion)

Despite one of the program's stated purposes being not to introduce additional or unforeseen hazards, neither the MOC form nor the procedure discussed several common mill facility hazards. Combustible dust, housekeeping issues as they related to combustible dust hazards, and fire hazards, for example, were not addressed.

The MOC form included a question regarding "any [e]ffect on capacity?" but otherwise no fields on the form mentioned items that would trigger review for unintended consequences of changes that could impact combustible dust hazards in the mill facility. There were no checklist questions to elicit discussion of production rate change effects, combustible dust hazards, dust collection systems, transport velocities in pneumatic conveying, or potential plugging in the process, although there were free-form blanks on the MOC form such as "brief description of change" that would have allowed space to discuss such topics if the originator chose to do so unprompted.

Food safety and quality were also a significant part of MOC review and approvals. Each change was reviewed by the plant manager and potentially two other "Management System Representatives": one for energy, environmental, PSM, and personal safety issues, and the other for food safety, quality, and transportation. The appropriate representative reviewed the change if the form indicated a "yes" response to one of the corresponding checklist items on the MOC form. The MOC procedure did not contain any provision for subject matter expert reviews, such as a reviewer for combustible dust hazards.

During a review of Didion's MOCs, the CSB noted a frequent lack of sufficient detail to fully describe the changes. Most of the MOC forms reviewed, including the temporary change above in effect the night of the incident, contained only single-sentence change descriptions, and only one change contained any attachments. The level of detail was insufficient to assess combustible dust hazards throughout the MOC process.

The CSB concludes that while food safety and quality may be incorporated into a Management of Change (MOC) program, Didion's MOC program did not effectively address known combustible dust hazards and was insufficiently designed to identify or address them. This likely contributed to the incident by allowing a temporary MOC to be installed without consideration of the potential consequences of that change. Didion's program lacked sufficient checks to ensure that safety hazards were appropriately and completely assessed, changes were designed and reviewed by qualified and trained personnel, and quality work was performed in compliance with the MOC program.

As discussed above in **Section 4.1**, Didion did not provide calculations or drawings demonstrating airflow re-balancing or adequate transport velocity for any changes to dust collection system ductwork or pneumatic conveying systems. For example, for the temporary cyclone discharge change that was in effect the night of the incident, there were no calculations or equipment design information attached to the temporary change documentation indicating that material loading and air transport velocity were adequate or even considered for the new design to convey the additional product from the North BM through a single transport line to 4B.

The CSB reviewed all change documentation forms that Didion provided for changes implemented during the five years preceding the incident. None of those changes included any sort of analysis for pneumatic conveying system or dust collector ductwork airflow balancing, minimum air transport velocity, or maximum product loading. Didion's lack of consideration for these factors was evident by the many deposits of material inside ductwork found after the incident, as noted in **Section 4.1** above. These deposits contributed to the incident severity by allowing combustible material to accumulate inside multiple locations in the facility's pneumatic transport and dust collection systems, enabling further flame front propagations to occur.

The CSB concludes that Didion's MOC procedure was not conducive to detecting or mitigating pneumatic conveying or dust collector hazards, or material accumulation inside ductwork, which are significant and well-recognized combustible dust hazards. Failure to account for these hazards when implementing changes in the mill facility allowed combustible dust to accumulate in multiple ductwork systems, among other things, contributing to the incident's severity.

4.6.3 Industry Guidance

4.6.3.1 Center for Chemical Process Safety (CCPS)

Several publications describe best practices for MOC programs. Among these, the CCPS provides MOC program guidance in its *Guidelines for the Management of Change for Process Safety*, as an example [66].

The CCPS notes that many companies have implemented protocols for addressing changes without regulatory requirements because such controls represent sound business practices for achieving safety, quality, and environmental objectives, but that MOC systems at many companies may lack the formal structure to help ensure that [66, p. 11]:

- Designs of site processes are well understood and documentation is up to date;
- Proposed modifications are routinely evaluated for potential safety and health impacts before being implemented;
- The level of detail for each review is appropriate for the potential hazard it poses;
- The appropriate level of company management authorizes the changes;
- Related activities required to safely implement the changes (e.g., training) are conducted;
- Training of personnel on the changes is effective; and
- Records are maintained to document the change.

To ensure an effective MOC program, the CCPS defines these key principles and essential features [66, pp. 22-25]:

- **Maintain a dependable MOC practice**
    - Establish consistent implementation
    - Involve competent personnel
    - Keep MOC practices effective
- **Identify potential change situations**
    - Define the scope of the MOC system
    - Manage all sources of change
- **Evaluate possible impacts**
    - Provide appropriate input information to manage changes
    - Apply appropriate technical rigor for the MOC review process
    - Ensure that MOC reviewers have the appropriate expertise and tools
- **Decide whether to allow the change**
    - Authorize changes
    - Ensure that change authorizers address important issues
- **Complete follow-up activities**
    - Update records
    - Communicate changes to personnel
    - Enact risk control measures
    - Maintain MOC records

Appendix B of the *Guidelines for the Management of Change for Process Safety* provides specific guidance in implementing the MOC system design structure above, including flexibility to tailor a program for a particular industry or site based on risk, company resources, and company culture [66, pp. 117-121].

The Didion MOC procedure and form omitted several critical elements of an effective MOC process, including, for example, applying appropriate technical rigor for the MOC review process. One way to address this is to provide a structure for the technical basis of each change. The CCPS defines "technical basis" as:

> [a]n explanation of the proposed modification, including the reason(s) for performing the work, desired results, technical design, and appropriate implementation instructions…. …the technical basis for change should be of sufficient detail to allow appropriate supervisory, technical, and management review, including addressing the following questions:
>
> • What is to be changed and how?
> • What will be achieved by the change?
> • How will the change achieve the intended goal?
> • Is the change safe to make and why? [66, p. 28]

For the temporary MOC form tying the North BM and South BM Cyclones' discharges together the night of the incident, had Didion answered the four questions above before implementing the change, Didion might have included calculations showing the transport line was capable of handling the extra product load. Didion also could have implemented the change in a different way, such as tying the North BM and South BM systems together on 4B instead of 1B, leaving both the North BM and South BM transport lines to 4B in service and eliminating the potential plugging hazard by not changing the pneumatic transport system portion of the process. Alternatively, Didion might have evaluated the change and concluded that, due to the much larger gap in the North BM compared with the South BM and the small target particle size of bran product, the system would not effectively "make more bran" in any case. Didion might even have canceled the change entirely.

Didion's MOC forms included little, if any, technical or engineering analysis or review for proposed changes to either ensure they did not present a new or previously unrecognized combustible dust hazard, or to mitigate such hazards if the proposed change introduced new hazards or changed existing ones. The form never mentioned combustible dust.

The CSB concludes that Didion's MOC program did not apply appropriate technical rigor for the MOC review process, and as a result, did not effectively address known combustible dust hazards. This likely contributed to the incident by allowing a temporary MOC to be installed without consideration for the potential consequences of that change, and by allowing combustible dust to accumulate in multiple ductwork systems, contributing to the incident's severity.

The CSB recommends that Didion upgrade its Management of Change (MOC) procedure to include clearer guidance and quality checks throughout the MOC process, following industry guidance such as that from CCPS's *Guidelines for the Management of Change for Process Safety*, including, at a minimum:

a. Require appropriate technical rigor for the MOC review process, such as guidance for a clear, complete technical basis (Appendix B).

b. **Make the MOC program more conducive to combustible dust hazard identification, such as by adding questions about common hazards in a dry corn mill like minimum transport velocity, potential for dust accumulation in dust collection and product transport systems, and propagation hazards so that all changes receive a more complete review for the appropriate hazards.**
c. **Clarify roles, responsibilities, and review processes in the MOC procedure, ensuring the reviewers are appropriate for the scope of each change.**
d. **Ensure that all MOC initiators and reviewers are qualified and trained.**
e. **Implement an audit program for MOC policy compliance and thoroughness to ensure appropriate level of detail, reviewers, and updated documentation are being used, and to identify and correct program gaps on an ongoing basis.**

4.6.3.2 NFPA

The NFPA provides guidance and multiple standards regarding MOC in facilities that handle combustible dust. NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities* (2017 edition), addressed MOC in Chapter 9.9: [6, p. 28]

> [T]he owner/operator shall require that a qualified person knowledgeable in the fire and deflagration hazards of agricultural dust be informed of changes (other than replacements-in-kind) to facilities, equipment, or processed materials before implementation of the change. […] The knowledgeable person shall consider whether or not the change would comply with NFPA 61 and if the change does not comply, then a method of compliance shall be determined.

Since its effective date in September 2015, NFPA 652, *Standard on the Fundamentals of Combustible Dust* (2016 edition), has had more comprehensive MOC requirements: [46, p. 25]

> Written procedures shall be established and implemented to manage proposed changes to process materials, staffing, job tasks, technology, equipment, procedures, and facilities.
>
> The procedures shall ensure that the following are addressed prior to any change:
> (1) The basis for the proposed change
> (2) Safety and health implications
> (3) Whether the change is permanent or temporary, including the authorized duration of temporary changes
> (4) Modifications to operating and maintenance procedures
> (5) Employee training requirements
> (6) Authorization requirements for the proposed change
> (7) Results of characterization tests used to assess the hazard, if conducted

More recently, in the 2020 edition of NFPA 61, MOC requirements have expanded to mimic parts of NFPA 652, and included similar language to NFPA 652 and items (1), (2) and (6) above, but the other requirements from NFPA 652 (2016 or 2019) are not required in NFPA 61 (2020) [23, p. 16].[a]

[a] The other four NFPA 652 requirements are listed in the (optional) annex A of NFPA 61 (2020).

NFPA 652 cites examples of when MOC would be required in other sections of the standard, such as for pneumatic conveying, dust collection, and centralized vacuum cleaning systems: “Where it is necessary to make changes to an existing system, all changes shall be managed in accordance with the management of change requirements” [46, p. 18]. These additional references, among other guidance and details, are missing from NFPA 61 (2020) [23].

The CSB concludes that NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, contains fewer MOC requirements than NFPA 652, *Standard on the Fundamentals of Combustible Dust*, such as addressing temporary changes, operating and maintenance procedures, employee training, and dust testing results, among other things. NFPA 61 also lacks general guidance, such as when to apply MOC, that NFPA 652 provides. These differences between the standards result in a less comprehensive and less effective MOC system in agricultural dust settings than in other industries, which are held to a higher standard in NFPA 652. Even if Didion had followed NFPA 61, it would have allowed the temporary MOC downstream of the North and South BMs to be implemented without a basis for the change, without full consideration of the safety and health implications, and without authorization by a knowledgeable, qualified reviewer. Had Didion’s MOC program been required to more thoroughly define the technical basis and safety and health implications, and have changes reviewed by a knowledgeable, qualified reviewer, the incident might have been prevented or mitigated.

The CSB recommends that NFPA harmonize the MOC requirements in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, or its successor, with MOC requirements and guidance currently in NFPA 652, *Standard on the Fundamentals of Combustible Dust*, and CCPS’s *Guidelines for the Management of Change for Process Safety*, such as addressing temporary changes, operating and maintenance procedures, employee training, and dust testing results, to standardize MOC requirements across all industries that handle combustible dust.

As discussed above in **Section 4.6.2**, Didion had an MOC policy, procedure, and form. Didion’s MOC system did not include all the elements noted above in standards NFPA 61 and NFPA 652. Absent from Didion’s procedure were some of the issues to be addressed in the MOC process, such as a technical basis for the proposed change, modifications to operating or maintenance procedures, communicating changes to affected employees, and maintaining and evaluating the ongoing effectiveness of the MOC system.

The CSB concludes that while Didion’s MOC program may have complied with NFPA 61 as it existed at the time of the incident, the program could be strengthened by incorporating NFPA 652 requirements and guidance, such as modifications to operating or maintenance procedures, maintaining and evaluating the ongoing effectiveness of the MOC system, and bases for changes and designs. Had Didion included such items in its MOC program, design issues such as insufficient transport velocity or connecting equipment without sufficient safeguards might have been detected through the MOC program, and the incident might have been prevented or mitigated.

The CSB recommends that Didion update its Management of Change procedure to meet or exceed NFPA 652 requirements for MOC and ensure that it adequately addresses combustible dust hazards such as dust accumulation in collection systems and product transport ductwork, propagation, and achieving adequate air transport velocity.

4.6.4 OSHA Requirements

OSHA regulations did not require Didion to have an MOC procedure for the mill facility when the incident occurred. OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not mention tracking or managing changes.

However, since Didion had combustible dust at the mill facility, following good practices for MOC could have avoided serious hazards. Guidance for implementing effective MOC programs was available for decades before the incident occurred.[a] Ensuring "that changes to equipment, process technology, chemicals, or facilities do not introduce additional or unforeseen hazards" was the stated purpose of Didion's MOC policy. NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, leads a reader to MOC guidance in NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, by reference as early as 1997.[b] The CCPS's guidance described above was available in 2008.

The CSB concludes that the lack of OSHA prescriptive requirements for MOC systems in grain handling facilities or other facilities with combustible dust hazards can result in process changes that create unrecognized hazards, leading to significant combustible dust incidents. Had Didion been required to maintain a robust MOC program, the temporary MOC downstream of the North and South BMs implemented the day of the incident, along with other changes that allowed combustible dust accumulation in dust collection systems, could have been more thoroughly reviewed and hazards mitigated, potentially mitigating the incident consequences.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates effective MOC programs, such as that outlined in CCPS's *Guidelines for the Management of Change for Process Safety.*

4.7 Incident Investigation

On the night of the incident, smoldering material downstream of the Bauermeister gap mills caught fire, traveled through the process, caused a dust collector explosion, and caused secondary dust explosions and flash fires throughout the mill facility, as described in **Section 3.1**. This was not the first time that such events had occurred at Didion, although they had not all occurred at once. In the years before the May 31, 2017 incident, Didion experienced near misses and smaller incidents indicative of safety hazards causal to the incident on May 31, 2017. In some cases, Didion investigated these incidents and near misses.

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[a] Management of Change was first mentioned in NFPA 68 in 2007 and in NFPA 654 in 1997. The 1999 edition of NFPA 61 references NFPA 654 (1997 edition).

[b] The 1999 edition of NFPA 61 references the 1997 edition of NFPA 654, which lists management of change requirements. Later editions of the standards are referenced above to exemplify readily available standards well before the incident. The 2013 and 2016 editions were not used for this purpose to show that even if only older editions of the standards were used, the result would have been the same.

4.7.1 Didion's Incident Investigation Program

At least as early as September 2012, Didion had a procedure titled "Incident Management" that required performing incident investigations "to capture and report illness/injuries, deaths, property damage, chemical spills, and near miss events." Included in Didion's procedure were the following definitions, indicating the scope of events to be investigated using the Incident Management procedure:

- Incident - an event leading to illness, injury, death, property damage, chemical spills, or a near miss.
- Property damage - damage to Didion property including fire.
- Near miss - an event that could have led to the injury or death of a worker but did not result in any injury.

The Incident Management procedure discussed completion of investigation forms, evidence gathering and preservation, immediate actions to take such as first aid or emergency care to victims, whom to notify, and light duty accommodations. It did not include tracking incident action items that resulted from the investigations.

The CSB requested copies of previous incident investigation reports, including "follow-up tracking the implementation of the corrective actions." Didion provided investigation reports going back to 2012, but the reports provided by Didion did not include follow-up actions or corrective action tracking. Didion's policies and procedures at the time of the incident did not appear to include a tracking system or guidance for developing incident corrective actions, or for evaluating their effectiveness.

4.7.2 Prior Incidents

Gaps in Didion's incident investigation program were highlighted by a series of incidents and near misses that foreshadowed the May 31, 2017 incident. If Didion had fully investigated and effectively corrected or mitigated the hazards in these incidents, the May 31, 2017 incident could have been prevented.

South Bauermeister Fire

On October 18, 2012, smoke and burning embers were observed in the bottom of the South BM gap mill in 1B. Employees called 911 due to extensive smoke, and the local fire department responded. The plastic sight glass in the South BM receiving cyclone was melted, and the air intake filter for the South BM discharge line blew off, with flames coming out of the line. A mechanic quickly installed a piece of sheet metal in the exhaust ductwork from the cyclone to prevent a fire spreading to the Torit Filter. Didion's investigation determined that the causes were "blockage in the Bauermeister caused a lack of flow through the system and embers developed inside the machine" and "lack of ability to determine if the Bauermeister hopper is blocked." No injuries occurred due to this event. The investigation recommendations are shown in **Figure 61**.

REMEDIAL ACTION			
Describe the Actions taken and follow-up that will be taken to prevent recurrence			
Corrective Follow-up Action Required	Action By: Last Name, First Initial	Compliance Date	Completed Date
1. Develop Standardized Start up Procedure for the Bauermeiester		10/23/2012	
2. Add Additional Level Indicator and Heat Sensors		10/23/2012	
3. Automate the system to shut down if heat sensor reads atypical readings		10/26/2012	

Figure 61: Follow-up actions for the South BM fire in 2012. (Credit: Didion)

There are several similarities between this incident and the May 31, 2017 incident: a fire developed in or near the South BM discharge line, the transfer line air intake filter blew off, and the fire moved through the piping. This incident was an opportunity to address a fire in a pneumatic transport line reaching the downstream dust collector, but the incident report does not mention this hazard, despite a mechanic recognizing the hazard and acting on it during the incident. The report also did not mention the potential for this scenario to occur with similar equipment at the facility including the North BM, even though the equipment was just a few feet away from where this incident occurred.

The corrective actions from the 2012 incident addressed plugging detection and prevention in the South BM, but no other effects were considered, such as those downstream of the South BM, the potential impact to dust collectors should embers reach them, or the potential for a similar incident to occur in any other equipment in the facility.

The corrective actions appear to have been implemented based on the CSB's review of photographic evidence and Didion's drawings and control system graphics. However, it is unclear whether the choke sensors[a] installed as corrective actions to the 2012 incident were operating at the time of the May 31, 2017 incident. The CSB received process data for some of the choke sensors and temperature readings on the South BM for May 2017, but not the choke sensors in the line and cyclone downstream. No choke sensors alarmed in the South BM or anywhere else in the Bran system on the night of the incident.

The CSB concludes that after a 2012 South BM fire, Didion did not recognize the significant hazard that smoldering material reaching a downstream dust collector posed, and consequently did not recommend or take corrective actions to prevent it. The CSB further concludes that Didion did not ensure that the resulting corrective actions were effective immediately after implementation or that they were effective over time, allowing this scenario to occur again during the May 31, 2017, incident.

[a] Didion used in-line sensors to detect material plugging a pipe, duct, or piece of equipment. Didion referred to these instruments as "choke sensors" or occasionally "plug sensors.".

Flash Fire near Torit Filter

On June 21, 2013, an employee sustained burns to his hands, arms, neck, and face due to a flash fire near the Torit Filter. The employee had finished greasing bearings on an overhead platform and as he descended the platform's ladder, a fugitive dust cloud ignited. The ladder was loose and moved, and the employee slipped and fell the last two rungs. Didion's internal investigation report notes that "the [ladder] tilted up and banged the catwalk. [Employee stated] all of a sudden there was a fireball." The employee "started to turn away and then the fire got louder and bigger. It burned out past where [employee] was standing." A nearby employee notified the supervisor when he saw smoke near the Torit Filter, but he did not see the injured employee, who was still on the overhead platform at the time. It was not clear from the report whether the smoke was observed before or after the fireball. Didion's investigation report classified this event as a "dust explosion," but the report does not mention any possible causes of the fire. The investigation report documented no recommendations related to the fire.

The injured employee was not wearing any fire-retardant clothing that might have reduced the severity of his burns. The incident investigation report did not acknowledge that an ignition source was present in a mill room that contained enough combustible dust to create a flash fire that engulfed an employee. While the ignition source was not identified in the investigation report, one potential ignition source was a natural gas burner for one of the dryers. A natural gas burner is a significant ignition source to be located inside a mill room that contained corn dust deposits. Despite these circumstances, the incident investigation did not discuss the possibility of controlling ignition sources, or any other corrective action that might prevent recurrence. This incident also did not drive any changes to personal protective equipment (PPE) needs.

The CSB concludes that Didion's incident investigation into a 2013 flash fire did not identify any gaps regarding controlling ignition sources or personal protective equipment for mill operations employees. Didion's incident investigation made no connection to the inherent flash fire and explosive hazards of corn dust as a result of this incident, and therefore no relevant corrective actions were created, assigned, or completed, which could have prevented or mitigated the consequences of the May 31, 2017, incident.

Fires in Discharge of Size Reduction Equipment[a]

In the years preceding the May 31, 2017, incident, Didion experienced a series of fires in milling and grinding equipment and associated discharge piping throughout the mill facility. Four known fires that occurred in the discharge piping downstream of a piece of size reduction equipment had common factors that Didion could have learned from and addressed before the May 31, 2017, incident. Each incident involved material plugging in the equipment's discharge line, and then smoldering and ultimately catching on fire.

By its nature, any cutting, milling, or grinding operation will generate heat [35, pp. 175-176]. Pneumatic transport away from this equipment dissipates that heat via airflow [67]. When that airflow is blocked or restricted, the heat cannot dissipate, the material inside the mass of a plugged line is insulated by the material itself, and the heat buildup can cause a fire [8, p. 34].

[a] All manner of milling or grinding equipment, including but not limited to roller mills, gap mills, hammer mills, etc., are collectively referred to in this section as "size reduction equipment."

On August 21, 2013, a fire occurred in a hammer mill in the pregelatinized corn meal (PCM) Process due to an obstruction in the discharge ducting. Didion identified the cause as "too much product and it [choked] the hammer mill." The investigation report listed the corrective actions as "slow down the feeder," "check more often the lift line," and "install a [choke] sensor on the lift line."

On May 20, 2014, a fire occurred in 1B at the exit of the Fine Grinder,[a] part of the PCM Process. According to the Didion incident report, the Grinder discharge (lift) line[b] plugged, and the material began to smolder. As the system was being cleaned up, "the flames started to go [through] the line…" but were put out with a fire extinguisher and the system was shut down to stop the fire spreading. The corrective action was to "order a plug sensor and enter work order for installation." Prior to this 2014 incident there were no such sensors in this line.

On May 21, 2014, a fire was found under the bran roll stand.[c] According to Didion's internal incident report, the fire's cause was choke sensor failure. Material in the piping and the roll stand was found smoldering. The fire department was notified, sprayed water on the roll stand to cool it, and checked the system with an infrared thermometer. The investigation's corrective actions were to repair and relocate the choke sensor and add more fire training to operator orientation.

On June 10, 2014, a near miss occurred, and Didion issued a report stating that "bran stayed in [the] Bauermeister too long" causing the material to begin to smoke inside the South BM. Didion's investigation attributed the cause to four choke sensors that failed to indicate the discharge (lift) line was plugged. The documented corrective action was to calibrate the choke sensors.

The four incidents above were opportunities to address the conditions that caused these types of fires. Instead, however, the recommendations were aimed at preventing plugging by slowing down equipment feed rates or detecting plugged lines more quickly using choke sensors, rather than preventing the conditions that led to plugged lines in the first place. Even if the corrective actions had been implemented, the CSB found no evidence of effective communication to employees to alert them to the safeguards' purpose or importance. Indeed, even for the May 31, 2017 incident, Didion was unable to provide any choke sensor data for the South BM and its discharge line, despite the control computer graphic indicating that four choke sensors existed in the South BM and its discharge line. Each incident had corrective actions involving adding or calibrating choke sensors, or ensuring that choke sensor alarms were functional. Yet even in the May 31, 2017 incident, choke sensor data were not available because it appears the choke sensors were nonfunctional. Given the history of fires in size reduction equipment discharge lines over the five years before the May 31, 2017 incident, this appears to have been a common, but tolerated, hazard at Didion.

The CSB concludes that although Didion had a known, chronic issue with size reduction equipment discharge lines plugging and causing a fire, Didion did not effectively address this safety hazard. Previous incidents involving this hazard were not thoroughly investigated and did not result in effective corrective

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[a] The "Fine Grinder" referred to in the incident report, M-12158, could not be identified post-incident. The CSB believes this is the same or similar equipment to the "Fine Grinder" in the PCM process, M-12227, which was simply a smaller-sized Bauermeister gap mill than those described above in detail. Based on the HACCP block diagrams provided, this was the only "Fine Grinder" in service by the time the incident occurred.

[b] Didion called a "Lift Line" any product transfer line using vacuum to pull product through a line, and a "Blow Line" a pressurized product line pushing product through the process, similar to the vacuum transfer and pressure transfer described in **Section 2.2.2.2**.

[c] A "roll stand" was simply another term Didion used for a roller mill. Roller mills consist of "two cylindrical steel rolls mounted horizontally, vertically or diagonally, and aligned in parallel to each other, which are rotating in opposite directions" [33, p. 102].

action that prevented recurrence, such as the likely starting point of the smoldering fire on the night of the May 31, 2017, incident.

<u>Fire on May 29, 2017</u>

Two days before the May 31, 2017, incident, Didion experienced a fire in a dryer located in C Mill and its dust collector on the B Mill roof. Equipment was damaged due to the fire, but no one was injured. Because workers were not able to extinguish the fire on their own, mill facility personnel evacuated and called the fire department. The fire progressed to the dust collector downstream of the dryer, located on the B Mill roof, which the fire department eventually put out with the aid of a ladder truck.

According to Didion's investigation, the fire began with a "material accumulation under [the] perforated fluid bed plate" of the dryer due to insufficient airflow and the presence of fine dust. Because the airflow to the downstream dust collector also continued, a burning ember from the dryer bed likely made its way into the dust collector as well, setting it on fire (**Figure 62**).

Figure 62: May 29, 2017, process fire during event (left) and following event (right) on B Mill roof. (Credit: Didion)

According to a Didion employee, the equipment involved in the fire was, "completely self-contained, so only the… equipment [that] goes to the filter caught fire. So it could not have spread to… any other dust collection system." The affected part of the process remained shut down afterward; Didion was actively investigating the cause of the May 29 fire when the May 31, 2017, incident occurred.

This incident could have been another opportunity to recognize significant hazards present at the mill facility and address them before a catastrophic incident occurred. While the CSB found no evidence that the two incidents were directly related, what happened at the C Mill dryer and its dedicated downstream dust collector on May 29 could have alerted Didion that the potential for a similar incident existed in other locations in the mill facility, such as the Dry Grit Filter. However, Didion restarted the facility approximately six hours after the May 29 fire, before completing the incident investigation.

While not likely related to the May 31, 2017, incident, the May 29 incident indicates that Didion restarted the other mill processes before its internal investigation was complete, rather than assuring that similar process hazards elsewhere in the mill facility were adequately mitigated and the incident was fully understood. The employees who reported for the night shift on May 31, 2017, did not receive any formal communication alerting them to watch for hazards similar to the incident two days before. Didion management did not perform a safety stand-down or safety pause to review the incident with hourly shift employees. This was an opportunity for Didion to communicate combustible dust hazards to employees working inside the mill facility, but no formal communication was issued.

Near Miss on May 31, 2017

On the morning of the incident that is the subject of this report, Didion experienced another near-miss event of smoldering material. According to Didion's investigation, the cause was a plugged line from a hammer mill in 1B,[a] resulting in material backing up into the hammer mill. The material began to heat up and then burn. While a fire did not fully break out in this case, this near miss is similar to the incidents above involving size reduction equipment discharge line plugging, material smoldering, and a fire.

Many day shift employees interviewed by the CSB recalled the May 31 near miss, but still called this a "normal day." The incident did not appear to be a concern for several mill employees, indicating that Didion had normalized these types of incidents.

Corrective actions had not yet been pursued by the time the 11:00 p.m. incident occurred, but this near miss was another opportunity for Didion to conduct a safety pause or stand down, or at least to communicate to the oncoming shift that night that this near miss had occurred. The CSB could not identify any employees on site that night during the incident who were aware of the near miss on the previous shift.

The CSB concludes that Didion's investigation of prior incidents was severely inadequate. Didion experienced incidents that were similar to or nearly identical to the May 31, 2017, incident at least six times in the previous five years, but Didion never took appropriate action to prevent recurrence. Process fires became normalized at Didion, which contributed to the response during the night of the incident.

4.7.3 Industry Guidance

Industry guidance on incident investigation management systems is available through the NFPA and CCPS.

[a] This hammer mill incident was near the North BM and South BM on 1B but occurred inside an unrelated process.

4.7.3.1 NFPA 61

Starting with the 2017 edition, NFPA 61, *Standard for the Prevention of Fire and Dust Explosions in Agricultural and Food Processing Facilities,* requires an incident investigation program with the following elements [6, p. 28] [23, p. 16]:

- The owner/operator shall have a system to ensure that incidents that result in a fire, deflagration, or explosion are reported and investigated in a timely manner.
- The investigation shall be documented and include findings and recommendations.
- A system shall be established to address and resolve the findings and recommendations.
- The investigation findings and recommendations shall be reviewed with affected personnel.

As discussed above in **Section 4.7.1**, Didion's Incident Management procedure did not include developing corrective actions to prevent incident recurrence, tracking corrective actions generated from investigations, or evaluating their effectiveness. The CSB found no evidence of communication to affected employees regarding learnings or corrective actions from previous incidents, as discussed in **Section 4.7.2**.

4.7.3.2 NFPA 652

Starting with its first (2016) edition, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, contained the identical requirements for incident investigation management systems as NFPA 61 above. Thus, guidance was available through NFPA standards starting in 2015 when the first edition of NFPA 652 was issued [46, p. 25] [22, p. 8.11].

Beyond the basic requirements above, both NFPA standards contain optional guidance[a] to aid an owner/operator in developing an effective incident investigation management system. The guidance in NFPA 652 is more extensive than in NFPA 61, such as:

> The investigation should include root cause analysis[b] and should include a review of existing control measures and underlying systemic factors. Appropriate corrective action should be taken to prevent recurrence and to assess and monitor the effectiveness of actions taken…. Corrective actions resulting from investigations should be implemented in all areas where there is a risk of similar incidents and subsequently checked to avoid repetition of injuries and incidents that gave rise to the investigation [46, pp. 57-58].

[a] Many NFPA standards, including NFPA 61 and 652, contain "requirements" (in the sense that in order to be NFPA standard compliant, these parts of the standard must be followed) in the main body of the document, with Annex material which is "not a part of the requirements of this NFPA document but is included for informational purposes only [6, p. 28]." "Optional guidance" mentioned in this section of the report refers to the Annex material.

[b] Root cause analysis is defined as "a technique for determining the ultimate cause of an accident [89, p. 178]."

4.7.3.3 Center for Chemical Process Safety (CCPS)

The ultimate goal of incident investigation is to prevent future incidents by communicating and applying the learnings from present investigations. CCPS's *Guidelines for Investigating Process Safety Incidents (3rd Edition)* states that: [68, p. 47]

> Effective incident investigation can best be accomplished by establishing an investigation management system that assists in achieving the following seven objectives:
> 1. Encouraging employees to report all incidents, including near misses.
> 2. Ensuring that investigations accurately determine what happened.
> 3. Ensuring investigations accurately identify causal factors and root causes.
> 4. Ensuring investigations identify and recommend preventive measures that reduce the probability of recurrence and/or mitigate as appropriate for the potential consequences.
> 5. Communicating the investigation findings.
> 6. Ensuring follow-up actions are taken to resolve all recommendations.
> 7. Establishing continuous improvement practices that evaluate effectiveness of recommendation implementation and the overall management systems.

The CSB concludes that Didion did not incorporate available industry guidance into its Incident Management procedure that might have prevented or mitigated the consequences of the May 31, 2017, incident. Didion's Incident Management procedure lacked guidance and a system to track and resolve incident investigation findings and recommendations, a process to review findings and recommendations with affected personnel, effective root cause analysis, review of existing control measures and underlying systemic factors, and a system to ensure that corrective actions adequately prevented recurrence or monitored the effectiveness of actions taken. Had Didion incorporated available industry guidance for incident investigations, Didion could have further investigated prior events and implemented effective corrective actions that could have mitigated or prevented the May 31, 2017, incident.

The CSB recommends that Didion develop and implement an effective incident investigation management system, incorporating the requirements and guidance of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, and the CCPS's *Guidelines for Investigating Process Safety Incidents*. The program should include a system to address and resolve incident investigation findings and recommendations, a process to review findings and recommendations with affected personnel, effective root cause analysis, review of existing control measures and underlying systemic factors, and a system to ensure corrective actions adequately prevent recurrence and to monitor the effectiveness of actions taken.

Accurately identifying causal factors and root causes and reducing the probability of recurrence are some of the items that the CCPS has identified as critical to an effective incident investigation management system. Unfortunately, these are just optional guidance in NFPA 652 [22, pp. 55-56] and are not included in NFPA 61 at all [23].

The CSB concludes that the NFPA guidance for incident investigation management systems has gaps that allow some combustible dust incidents to continue to occur. These gaps include not requiring that causal factors and root causes be accurately identified and not ensuring that investigations identify and

recommend preventive measures that reduce the probability of recurrence and/or mitigate as appropriate for the potential consequences. Had Didion incorporated CCPS's guidance for incident investigations, Didion could have more accurately identified causal factors in previous incidents, reduced probability of recurrence, and mitigated or prevented the May 31, 2017, incident.

The CSB recommends that NFPA adopt as prescriptive into NFPA 61, or its successor, more comprehensive guidance for incident investigation management systems, such as the optional sections of NFPA 652 and that in CCPS's guidelines. At a minimum, the additional guidance should include accurately identifying causal factors and root causes and reducing the probability of recurrence.

4.7.4 DIDION INVESTIGATION GAPS

According to the CCPS, the seven objectives described above in **Section 4.7.3.3** are essential to maintaining a well-designed incident investigation program. This section describes where these objectives were missing from the incidents described above. **Table 6** summarizes the types of incidents and the hazards present during prior incidents at Didion as discussed in **Section 4.7.2**.

Table 6: Summary of prior Didion incidents. (Credit: CSB)

Date of Incident	Incident Description	Hazard(s) Present
October 18, 2012	Smoldering fire in South BM discharge line which propagated through piping	Smoldering Fire and Propagation
June 21, 2013	Combustible dust flash fire in building during maintenance activities	Flash Fire
August 21, 2013	Smoldering fire in hammer mill	Smoldering Fire
May 20, 2014	Smoldering fire in small gap mill discharge line	Smoldering Fire
May 21, 2014	Smoldering fire in grinder discharge line	Smoldering Fire
June 10, 2014	Smoldering fire in South BM discharge line	Smoldering Fire
May 29, 2017	Fire inside dryer and smoldering embers transported to dust collector	Smoldering Fire and Fire
May 31, 2017	Smoldering fire in hammer mill discharge line	Smoldering Fire

Ensuring that investigations accurately determine what happened

Although Didion utilized an incident timeline during its investigation of the May 29, 2017 dryer fire,[a] and engaged a cross-functional team, only the shift supervisor investigated many of the previous incidents, and only a few sentences in the incident report described what happened. Especially for the flash fire near the Torit Filter, which represented an opportunity to address several serious hazards, the investigation report was only a few sentences long and did not include an analysis of what happened.

Ensuring investigations accurately identify causal factors and root causes

In the May 29, 2017 dryer fire, incident analysis was underway when the May 31, 2017 incident occurred. However, the other incident reports discussed above did not include causal analysis or identify causal factors. None of the previous investigations fully identified the conditions that led to the incidents, frequently focusing

[a] As noted above, this incident's investigation was still in progress when the May 31, 2017, incident occurred.

on just the malfunction or absence of choke sensors, rather than investigating or addressing the conditions that led to plugged lines, such as inadequate airflow or excessive product loading.

Ensuring investigations recommend measures to prevent recurrence or mitigate consequences

In the incidents involving size reduction equipment discharge piping, similar corrective actions were identified for each incident, even though these actions appeared ineffective, given the recurring fires in size reduction equipment discharge piping. These corrective actions did not have the desired effect of reducing recurrence. Yet subsequent incidents made similar recommendations.

Additionally, Didion did not identify corrective actions that could have prevented or mitigated recurrence in some incidents because the cause was not fully recognized. For example, the South BM fire investigation did not identify corrective actions to prevent or mitigate a smoldering nest reaching a dust collector. As noted in **Figure 61**, the corrective actions focused on sensors in the South BM and discharge line, but these were nonfunctional the night of the May 31, 2017 incident. Likewise, the flash fire near the Torit Filter investigation did not identify corrective actions to control ignition sources or change mill operations employees' PPE. The corrective action identified in this incident report was only to provide a way for employees to clean dust off their clothes in the room.

Ensuring follow-up actions are taken to resolve all recommendations

Of the eight incidents discussed, only one had a corrective action assigned that included a due date, and the action was signed off as complete. Prior to the May 31, 2017 incident, Didion did not have a formal system to track and confirm the completion of incident corrective actions.

Evaluating effectiveness of recommendation implementation and overall management systems

For several hazards, repeat incidents continued to occur, with no recognition that the corrective actions were not preventing incidents. Incident learnings from one piece of equipment were not applied elsewhere in the mill facility in similar situations. Thus, several similar incidents, with similar corrective actions, continued to occur over several years in size reduction equipment discharge piping. Four fires occurred (in the discharge piping of a hammer mill, Fine Grinder, Bran Roll Stand, and the South BM), but none of these investigations recommended corrective actions to address similar hazards throughout the mill facility. Each investigation only discussed the specific piece of size reduction equipment involved at the time. Several of the previous incidents indicated a potentially catastrophic consequence if a fire reached downstream dust collection equipment, but this was not recognized or acted upon in the investigations.

Conclusion

Since Didion had combustible dust at the mill facility, following good practices for incident investigation could have avoided or mitigated serious hazards that ultimately caused the May 31, 2017 incident. Guidance to do so, and what such a program should contain, was available well before the incident occurred. For example, the CCPS's *Guidelines for Investigating Process Safety Incidents* dates back to at least 2003. NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, covers the mill facility, but it did not address incident investigation until 2016, after several of the incident examples discussed here occurred.

The CSB concludes that Didion's incident investigation management system did not thoroughly analyze hazards, accurately determine what happened, accurately identify root causes and causal factors, properly identify preventive measures, ensure that follow-up actions were taken, or evaluate corrective action effectiveness, and therefore was ineffective. Didion missed critical opportunities to address significant combustible dust hazards in previous incidents and near misses in the mill facility before a catastrophic event occurred. Had Didion thoroughly investigated these previous incidents and near misses, the May 31, 2017, incident may have been prevented or mitigated.

4.7.5 OSHA Requirements

OSHA regulations did not (and do not) require Didion to have an incident investigation management program for the mill facility. OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not require incident investigation.

The CSB concludes that the lack of OSHA prescriptive requirements for incident investigation management systems in grain handling facilities can result in unrecognized or improperly mitigated hazards, leading to significant combustible dust incidents. Had Didion been required to develop and implement an incident investigation program, Didion could have identified and corrected the repeated factors that contributed to the development of smoldering fires, flash fires, and explosions during the incident.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates requirements for effective incident investigation programs, such as that outlined in CCPS's guidance, *Guidelines for Investigating Process Safety Incidents*. The standard should include guidelines to:

- **a. Encourage employees to report all incidents, including near misses.**
- **b. Ensure that investigations accurately determine what happened.**
- **c. Ensure investigations accurately identify causal factors and root causes.**
- **d. Ensure investigations identify and recommend preventive measures that reduce the probability of recurrence and/or mitigate as appropriate for the potential consequences.**
- **e. Communicate the investigation findings.**
- **f. Ensure follow-up actions are taken to resolve all recommendations.**
- **g. Establish continuous improvement practices that evaluate effectiveness of recommendation implementation and the overall management systems.**

4.8 Process Safety Information

Process Safety Information (PSI) is "Physical, chemical, and toxicological information related to the chemicals, process, and equipment. It is used to document the configuration of a process, its characteristics, its limitations, and as data for process hazard analyses [8, p. xxii]." Accurate and complete PSI is critical to performing effective hazard assessments, managing changes, and safe operating decisions [69, p. 71].

4.8.1 DIDION'S PROCESS INFORMATION

The CSB requested information from Didion for a number of process or safety systems that Didion was unable to provide. For example, Didion was unable to produce information relating to the dust collection systems on the equipment involved in the incident, including requests for:

- Complete list of equipment used to remove dust particulates
- Didion personnel knowledgeable in the dust collection systems and management of fugitive dust control
- Engineering drawings
- Equipment manufacturers and specifications
- Installation plans and dates of installation
- Service records
- Testing data

Didion did not provide any documentation on engineering controls for combustible dust deflagrations. Photographic evidence of the equipment following the incident indicated the presence of deflagration venting installed on some equipment; however, Didion did not provide engineering details for these pieces of equipment.

In addition to engineering controls or design information, Didion was unable to provide a risk analysis for combustible dust hazard management (**Section 4.5**); combustible dust testing data (**Section 4.1.1**); corrective action plans for mill facility reconstruction DHAs (**Section 4.2.2**); post-reconstruction building design (**Section 4.4.3**); attachments, calculations, or drawing updates to any MOC documentation (**Section 4.6**); or corrective action tracking for incident investigations (**Section 4.7**).

Didion reported to the CSB that some records existed, but only in hard copy, and were destroyed in the explosions and building collapses, but did not specify any particular missing documents to which this applied, simply stating, "…many of Didion's documents were in paper format, and stored in mill offices that were completely destroyed in the incident."

The CSB concludes that had Didion electronically stored information, or stored it in a remote location, both Government and Didion investigators could have better evaluated the Process Safety Information involved in the incident, which is critical for conducting a high-quality incident investigation and identifying incident causes.

The CSB recommends that Didion incorporate recording any paper-based process safety information into Didion's existing electronic records management system so that the information can be reliably retained, retrieved, and analyzed in the event of a catastrophic incident.

4.8.2 PROCESS SAFETY INFORMATION GUIDANCE

In order to perform an effective DHA, for example, accurate and complete PSI is required. The CCPS identifies the following items as minimum needs in its *Guidelines for Combustible Dust Hazard Analysis*: [8, pp. 55-56]

- Dust particle size and size distribution data

- Combustibility and explosibility parameters [MEC, K_{St}, P_{max}, MIE, etc.]
- Process flow diagrams
- Process description
- Material and energy balances
- Process and instrument diagrams (P&IDs)
- Equipment layout
- Operating procedures
- Existing safety devices and interlocks
- Existing area classification diagrams
- Reports of previous incidents

The CCPS also identifies some common PSI-related warning signs of catastrophic incidents in its *Recognizing Catastrophic Incident Warning Signs in the Process Industries*. Some of these warning signs are listed in **Table 7**, along with Didion's systems deficiencies and the relevant section of this report.

Table 7: CCPS common PSI warning signs, compared to Didion's documentation and the relevant section of this report. (Credit: CCPS; CSB) [69, pp. 66-67]

PSI Deficiencies Identified by CCPS	Didion's Documentation Deficiencies	Report Section
Piping and instrument diagrams do not reflect current field conditions	Evidence of inaccurate P&IDs for dust collection ductwork systems	**4.1**
	Not updated with MOCs	**4.6**
Incomplete documentation about safety systems	No equipment deflagration vent calculations provided for equipment with deflagration vents	**4.3**
Inadequate documentation of hazards	No dust explosibility testing data for Didion materials pre-incident	**4.1**
Low precision and accuracy of PSI documentation other than piping and instrument diagrams	Dust collector concentration calculations incorrect	**4.1**
	Transport velocity calculations out of date, inaccurate in some cases	
PSI not readily available	Didion was unable to produce equipment, process, and building design information	**4.1 - 4.7**

NFPA 61 (2017 and 2020 editions) also discusses required PSI, which is similar to the CCPS's guidance above. Among other things, NFPA 61 requires documentation of "process and technology information" [6, p. 28] [23, p. 16], which it defines as:

> Process and technology information includes process performance parameters, properties of the materials being handled, and documents such as design drawings, design codes and standards used as the basis for both the process and the equipment, equipment manufacturers' operating and maintenance manuals, standard operating procedures, and safety systems operation [6, p. 47], [23, p. 46].

The CSB concludes that Didion did not maintain adequate Process Safety Information, which contributed to Didion's failure to identify, evaluate, and adequately address process hazards and implement adequate engineering controls and building design that could have prevented the incident or minimized its consequences.

The CSB recommends that Didion develop, implement, and maintain a Process Safety Information system to ensure that critical PSI is available for effective DHAs and other safety decisions. At a minimum, the PSI system should include:

- **a. means to ensure documentation is kept up to date,**
- **b. dust particle size and size distribution data,**
- **c. combustibility and explosibility parameters,**
- **d. process flow diagrams, process descriptions,**
- **e. process and instrument diagrams,**
- **f. equipment layout,**
- **g. operating procedures,**
- **h. safety devices and interlocks,**
- **i. area classification diagrams, and**
- **j. previous incident reports.**

4.8.3 OSHA Requirements

OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272, does not require companies to maintain PSI, assess combustible dust hazards, or conduct dust testing.

The CSB concludes that the OSHA *Grain Handling Facilities Standard* does not address the process safety or design information required to perform effective DHAs, hazard assessments, or safe operating decisions, which could mitigate combustible dust hazards such as those that resulted in the explosions and fires during the Didion incident.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates requirements for facilities to develop and maintain Process Safety Information, such as in the CCPS's *Guidelines for Combustible Dust Hazard Analysis* or NFPA 61 and NFPA 652 guidance. At minimum, this should include:

- **a. process performance parameters,**
- **b. properties of the materials being handled,**
- **c. design drawings,**
- **d. design codes and standards used as the basis for both the process and the equipment,**
- **e. equipment manufacturers' operating and maintenance manuals,**
- **f. standard operating procedures, and**
- **g. safety systems operation.**

4.9 MANAGEMENT OF EXTERNAL AUDITS AND INSPECTIONS

While most audits at Didion focused on food safety, Didion was audited by its insurance company and inspected by OSHA with a focus on combustible dust safety. Many findings generated by the insurance company and OSHA involved combustible dust hazards, the control of these hazards, and the standards required to prevent fires and explosions in the mill operations. **Table 8** summarized the findings of the audits and inspections that focused on combustible dust safety.

Table 8: Summary of findings during external audits and inspections at Didion. (Credit: Didion)

Inspection Authority	Inspection Year	Key Findings
OSHA	2010	• General Duty Clause[a] violation due to lack of engineering controls for dust explosion, deflagration, or other fire hazards.
Insurance Company	2012	• Inadequate electrical classification for combustible dust • Lack of explosion suppression equipment • Lack of explosion venting that vent to outside of building
OSHA	2013	• No General Duty Clause violation Issued • Hazard Alert Letter (HAL) issued with voluntary recommendations due to lack of engineering controls for dust explosion or other fire hazards. • Inadequate dust collector calculations

The findings had not been addressed at the time of the incident. Didion had not installed engineering controls (**Section 4.3**) to manage combustible dust hazards throughout the mill facility, and there is no evidence that any of these recommendations were addressed prior to the 2017 incident.

The CSB concludes that Didion did not have an adequate audit and inspection program to address the findings and recommendations that were generated from these actions. Furthermore, the deficiencies identified from the OSHA and insurance audits and inspections, if implemented in a timely fashion, could have mitigated the combustible dust fires and explosions that occurred during the 2017 incident.

4.9.1 DIDION AUDIT AND INSPECTION DETAILS

2010 OSHA Inspection

OSHA performed an onsite inspection in October 2010. As a result of the inspection, Didion was cited for a violation of the General Duty Clause due to hazards "associated with dust explosion, deflagration or other fire hazards." OSHA issued the citation based upon the lack of explosion protection systems, such as isolation, on multiple filter systems and lack of bonding on the pneumatic conveyance system. Among potential abatement methods provided by OSHA, compliance with NFPA 61, *Standard for the Prevention of Fires and Dust*

[a] The General Duty Clause is a requirement covered under the Occupational Safety and Health Act of 1970 in section 5(a)(1) which states "Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees [94]."

Explosions in Agricultural and Food Processing Facilities, NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, and NFPA 69, *Standard on Explosion Prevention Systems*, were listed.

The CSB concludes that years before the incident, OSHA identified inadequate deflagration engineering controls at Didion, but Didion did not address the hazards. Had Didion addressed the identified hazards, the incident could have been prevented or mitigated.

2012 Insurance Audit

In 2012, an insurance audit was performed on the Didion Cambria mill facility to assess potential hazards within the processes. The audit found a grain dust explosion risk due to the lack of Class II electrically classified equipment installed in all mill building areas. Additionally, the audit found a moderate grain dust explosion potential associated with the lack of explosion suppression or venting on the internal dust collector in the mill area at this location.

Following the audit, the insurance company also determined the largest loss scenario to be the potential from a dust explosion and subsequent fire in the B Mill area. The surrounding mill areas and warehouse could be affected due to the explosion and fire.

Findings from the audit include:

- Electrical installation in mill rooms not rated Class II for dust explosion hazard.
- Multiple fluidized bed coolers/heaters in various process rooms of the mill potentially have an atmosphere inside the equipment conducive to producing a dust explosion leading to possible subsequent secondary explosions throughout the mill.
- Possible lack of explosion venting in the mill area housing the dust collection cartridge system [Torit Filter]; it appears the dust collector has no direct venting to the outside.

The insurance company provided several recommendations for these findings. These recommendations include:

- Electrical installation in mill rooms should be Class II Div. 2 in accordance with the requirements of NFPA 70 – National Electrical Code. The company should consider hiring a qualified electrical engineer and contractor to evaluate existing installations as per NFPA 499. Proper boundaries around equipment should be proposed inside of which Class II Div. 2 electrical should be installed.
- Consider installing explosion suppression devices on fluid bed coolers. Perform an analysis on fluidized bed coolers to decide which coolers present the highest hazard and likelihood of a hot particle or ember entering the cooler.
- Provide documentation as to the existence of deflagration venting, and documentation that the dust collector meets the requirements of NFPA 68. If none exists, consider installing proper deflagration venting per NFPA 68.

The CSB concludes that Didion's insurance company identified several gaps related to combustible dust during the 2012 audit and provided recommendations to mitigate the hazards of these items. At the time of the incident, the lack of suppression and adequate venting increased the severity of the incident. Had Didion assessed the deflagration controls and electrical classifications, as identified by the insurance company, Didion could have implemented controls that could have mitigated the severity of the incident.

Didion's responses to the insurance company's recommendations and findings included:

- Samples will be taken of the product being processed and flow rates to determine if there is a combustible atmosphere inside the fluidized bed coolers/heaters. If necessary, suppression systems will be engineered and installed.
- All new systems would be engineered to comply with NFPA 61 and have safety monitoring systems.
- Calculations will be performed by Didion for the concentration of combustible dust in the transport ducting and various dust collectors.

The CSB concludes that the Didion responses provided for the insurance audit did not address the existing hazards within the mill facility. There was no evidence that any samples were taken of the material to determine if it was combustible dust. The response for engineering controls only indicated the application in future installations; however, there was no indication that any existing hazards would be addressed. Had Didion reviewed the existing systems for hazards and tested the materials for combustibility, Didion could have recognized the deficiencies in the safety systems that managed the combustible dust in the processes and implemented controls that could have mitigated the severity of the incident.

2013 OSHA Follow-up Inspection

OSHA performed an onsite inspection at the Didion facility in July 2013 to follow up on the 2010 inspection and the "lack of abatement information concerning the combustible dust citation." As a result of this inspection, OSHA expressed concerns in a letter to Didion's Vice President of Risk Management about the safety systems installed on the Dry Grit Filter.

> The explosion protection provided for the Grit dust collector did not include elements of deflagration isolation protection to prevent a potential deflagration occurring within the collector from returning back into the facility and upstream processes through the 'dirty air' ducting. It is our understanding that this unit likely collects material classifiable as (explosive) combustible dust. Enclosures such as this may have the potential for combustible dust to be present in sufficient quantity to cause enclosure rupture if suspended and ignited and have a potential method of suspending the dust since they are pneumatically pulsed.

Additionally, OSHA expressed concerns about — and questioned the validity of — the engineering analysis and MEC calculations (**Section 4.1.3**) performed for the Dry Grit Filter and other filters.

> This approach does not appear to be a valid, industry recognized approach for evaluating enclosed process equipment, especially a fabric filter media dust collector. These types of collectors suspend dust during pulsing events where a build-up of dust on filters is dislodged via mechanical or pneumatic means. During these dynamic cleaning events, dust concentration within the collectors can be near or above the MEC, especially near the filters. […] The analysis submitted does not appear to take this into account and is not consistent with industry recognized approaches for such a hazard analysis.

The CSB concludes that Didion did not appropriately address the OSHA inspection recommendations from 2013 to assess combustible dust and mitigate the identified hazards. Additionally, Didion did not

have an audit program that assigned responsibility to employees for follow-up on the action items. Had Didion incorporated engineering controls using engineering standards and guides, such as NFPA 61, NFPA 68, and NFPA 69, the incident could have been prevented or mitigated.

4.9.2 Audit Program Guidance

4.9.2.1 Center for Chemical Process Safety (CCPS)

The CCPS provides guidance on audits and audit programs in the *Guidelines for Auditing Process Safety Management Systems*. Audit findings should be addressed in a timely[a] manner and documented to ensure completion. An action plan should be developed to include timetables for completion, identify the person responsible for resolution of the recommendation, and require documentation of the tracking. Audit recommendations should be assigned to a responsible party for resolution and implementation of a given finding. The assignment of these actions should "be described in terms of actual names or titles…" and not a general group that is too broad for tracking. Audit recommendations should be tracked for status and updated to indicate what actions have been taken to correct the finding [70, pp. 68-71].

The findings of the audits and inspections were provided to senior leadership at Didion, such as the Vice President of Risk Management. From the 2010 inspection until the incident in 2017, multiple management changes occurred at the Didion facility. The changes in management, in conjunction with the dates of the inspections and audits, are outlined in **Figure 63**.

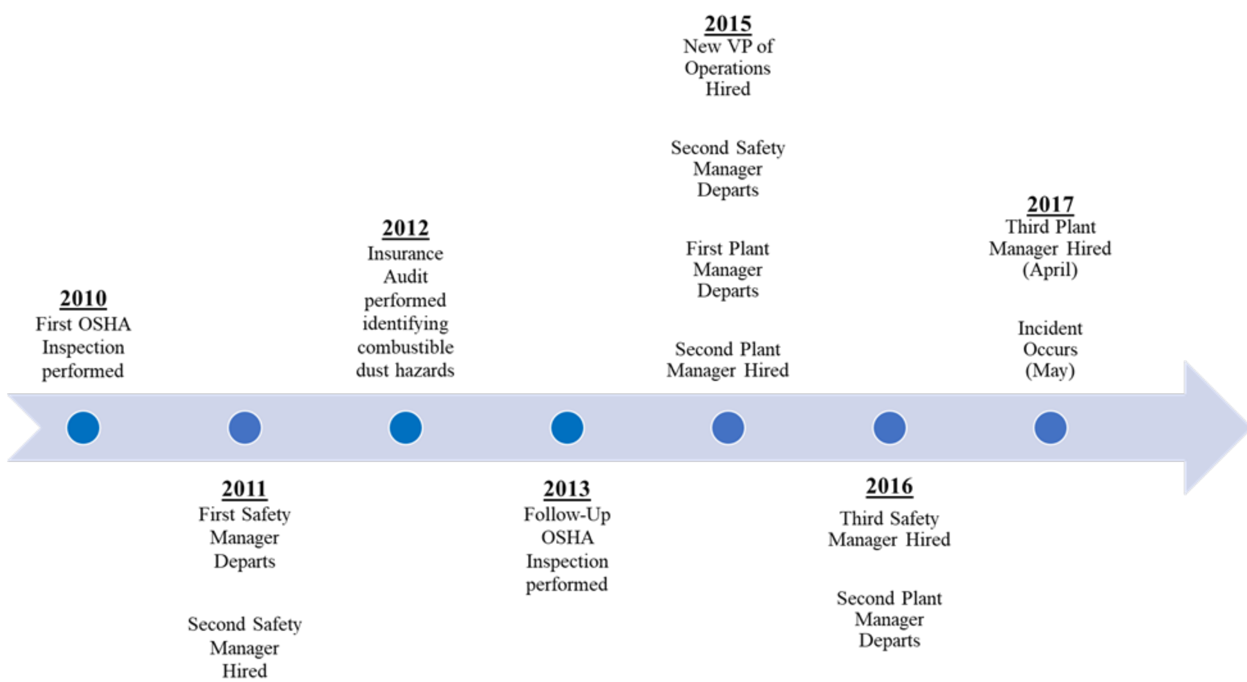

Figure 63: Timeline of audits and management changes at Didion leading up to the incident. (Credit: CSB)

[a] The CCPS defines timely as "… reasonable time period given the complexity of the actions or activities decided upon and their difficulty of implementation, and that the time should be evaluated on a case-by-case basis [70]."

Following multiple changes in the mill facility safety and operating management, the findings and recommendations were not disseminated to new management employees. Based upon the statements of multiple Didion employees, including the safety manager and the vice president of operations, they were unaware of the prior findings from the OSHA inspections related to the deficiencies of the combustible dust hazards in the mill. Regarding the 2013 OSHA letter to Didion and addressing the deficiencies identified, one employee stated, “I had no knowledge of that.” Furthermore, in response to the actions taken to comply with the letter, the employee responded that they were unaware of the actions taken for compliance with the recommendations.

According to Kletz, a renowned process safety expert:

> Organizations have no memory. Only people have memories and after a few years they move on, taking their memories with them. Procedures introduced after an accident are allowed to lapse, and some years later the accident happens again, even on the plant where it happened before. If by good fortune the results of an accident are not serious, the lessons are forgotten even more quickly [71, p. 529].

In the case of Didion, it is apparent that the management was either unaware or had forgotten the recommendations and the warnings of combustible dust hazards in the years before the incident. Furthermore, those recommendations and findings were not reviewed during the personnel changes in the mill facility. Had these recommendations been reviewed with employees with new and different backgrounds, the importance of addressing the hazards could have been recognized.

The CSB concludes that the lack of involvement and transfer of knowledge from upper management to the milling employees hindered the awareness of the combustible dust hazards present within the mill. The CSB concludes that the Didion audit process did not account for the turnover of personnel that should have triggered the re-assignment of actions to ensure the completion of critical recommendations that could have prevented or mitigated the incident. Had Didion ensured the transfer of knowledge and re-assignment of action items, Didion management could have been aware of prior inspections, which identified deficiencies in the management of combustible dust, and implemented recommendations that could have prevented or mitigated the incident.

The CSB recommends that Didion develop an effective audit program by implementing guidance for audit follow-up, such as those in the CCPS's *Guidelines for Auditing Process Safety Management Systems*. The audit program should include third-party audits for combustible dust hazards, a personnel management of change process to ensure action items are transferred when changes in personnel occur, and a review process for affected employees.

4.9.3 Gaps in Audit Program Requirements

The OSHA *Grain Handling Facilities Standard* does not require the performance of audits against safety requirements. The standard also does not require a facility to address any recommendations that could be generated from an audit.

The CSB concludes that OSHA's *Grain Handling Facilities Standard* does not adequately require facilities to either undergo safety audits or address safety recommendations as part of the regulatory

requirements. Had Didion been required to undergo safety audits and address recommendations, Didion could have been required to address deficiencies in its facility related to combustible dust, which could have prevented or mitigated the severity of the incident.

Such requirements are included in OSHA's PSM standard governing highly hazardous chemicals. Combustible dust incidents are no less hazardous or catastrophic than incidents involving PSM-covered materials.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that incorporates requirements for audits and inspections, including industry guidance, such as the guidance in the CCPS's *Guidelines for Auditing Process Safety Management Systems*.

4.10 Emergency Preparedness

On the night of the incident, Didion employees spent approximately 30 minutes trying to identify the source of the smoke that had been observed in the mill. The employees were unable to locate the source and as a result were unable to address a potential fire in the incipient stages with a fire extinguisher. No one attempted to shut down the mill processes or evacuate the mill facility until fires were observed on 1B.

When fires were observed, multiple employees were on the radio at the same time, resulting in confusion and delays in evacuating the facility. The radios were the only way for the emergency evacuation to be communicated to all of the employees across the facility. Furthermore, the radios used multiple channels based on the job type and the location within the mill, which led to additional delays in notifying employees of the emergency and the need to evacuate.

First responders from multiple jurisdictions were onsite following the first notifications of the fire and explosions at Didion. First responders noted continued fires for several hours during initial response activities, with most of the fires extinguished on the morning of June 1, 2017. There were no injuries to emergency response personnel during the incident response.

4.10.1 Didion's Emergency Response Program

4.10.1.1 Didion Emergency Response Plan

Didion maintained an emergency response plan for the Cambria, Wisconsin site. The response plan included a purpose, scope, definitions, roles and responsibilities, and procedures to follow for each type of emergency. Emergency situations considered were: "fire, spills, natural gas leaks, terrorist action, tornado, or any other situation that may place the occupants of a building at risk." **Figure 64**, below, depicts the fire response procedure at Didion and the directions for employees to call for external assistance after two fire extinguishers are used when fighting a fire. Employees were allowed to use discretion when contacting external assistance prior to the use of fire extinguishers.

4. PROCEDURE and/or PROCESS FLOW
   4.1. All personnel should proceed to their proper rally points based on the type of emergency at the facility. These emergencies include: Fire, Spills, Natural Gas Leaks, Terrorist Action, Tornado, or any other situation that may place the occupants of a building at risk.
      4.1.1. Ensure Visitors and Contractors are escorted to the rally points.
      4.1.2. Buddy system to ensure the safe exit of impaired personnel.
   4.2. All emergencies will be announced over the radio.
   4.3. Personnel with radios will communicate within their departments to assure that all employees are notified with one employee communicating with the Incident Commander. Incident command is in sole control of the situation and instructions must be followed as they are issued.

   4.4 **Fire or Terrorist**
      4.4.1 In the event that a Fire is detected contact your supervisor to alert all staff immediately.
      4.4.2 If a fire is detected you may call 911 at any time! You MUST call 911 by the time a second extinguisher is discharged.
      4.4.3 Evacuate out nearest fire exit door. Rally point for all personnel will be the grassy area near the Ethanol entrance road and Cabbage road or, if that location is deemed unsafe, the alternate location at the parking lot in front of the mill near Hwy 146. (see REF-CORP-SFTY-0005 Fire Evacuation Map)
      4.4.4 RCPF employees will be notified by scale operator or grain buyers by radio.
      4.4.5 Scale operators will notify and ensure grain delivery drivers located at the probe area are escorted to the rally point for fire evacuation, Safety Hill or alternate.
      4.4.6 RCPF employees will notify and ensure grain delivery drivers located at the pits are escorted to the Safety Hill or alternate.
      4.4.7 RCPF employees will take attendance of all employees and drivers present and radio names to scale operators or grain buyers.
      4.4.8 Sign-in at the rally point (Look for an Orange Vest Person) and ensure that all signed-in personnel stand separate from people who need to sign in.
      4.4.9 After sign-in and wait for additional instructions.

Figure 64: Didion Emergency Response Plan excerpt. (Credit: Didion)

The Didion emergency response plan treated the response to fires and terrorist attacks with the same steps of response. The Didion emergency response plan addressed the response to identified fires within the facility once the fire had been located. The Didion emergency response plan did not specify when a situation should be considered an emergency or what the acceptable operating margin is for troubleshooting prior to triggering an emergency response. For example, the Didion emergency response plan did not directly address what to do when a fire cannot be located. Furthermore, Didion did not identify when an upset condition, such as smoldering material, becomes an emergency that could trigger an evacuation. The emergency response plan covered using fire extinguishers for incipient fires and when to contact the fire department; however, the emergency response plan did not identify the correct response if employees identify an upset condition, such as a potential fire, but cannot locate it. Didion relied on radio communications between control rooms and certain employees to initiate the facility evacuation, but not all employees were supplied with radios during the work shift. Furthermore, Didion did not have a facility-wide alarm system to notify employees of a potential emergency. Rather, Didion relied on communication between the employees with radios and control rooms to disseminate information about potential evacuations or other critical information during an upset.

During the incident, employees spent at least 30 minutes trying to locate the source of smoke within the mill; however, the emergency response procedures lacked specificity on how to respond to this upset condition, when to trigger a process shutdown, and when to evacuate employees to mitigate the potential severity of an incident in the mill. Furthermore, there were no emergency shutdown procedures for the process to mitigate the ongoing fire in the process equipment.

Key Lesson

A fire inside an enclosed combustible dust handling process should not be considered an incipient fire because it cannot be characterized without the risk of increasing the severity of the incident.

The CSB concludes that Didion did not provide specific instructions to employees for abnormal conditions in its emergency response plan, such as the smoldering material and unidentified smoke sources. Furthermore, the emergency response plan did not identify when to notify employees to evacuate the facility or how to notify all employees. The lack of a defined response for upset conditions likely contributed to the severity of the incident.

The CSB recommends that Didion update its Emergency Response Plan to provide instructions for notifying employees of an upset condition and responding to fire scenarios with no apparent source.

4.10.1.2 Didion Emergency Response Training

The training provided for the emergency response plan instructed that during a fire all employees "…should proceed to the designated rally point." However, the emergency response plan did not specify what event triggers an evacuation, other than using fire extinguishers. Furthermore, a different Didion personal safety training package described the requirements within the Didion milling operations. **Figure 65** shows an excerpt of the training provided to employees regarding the emergency response plan.

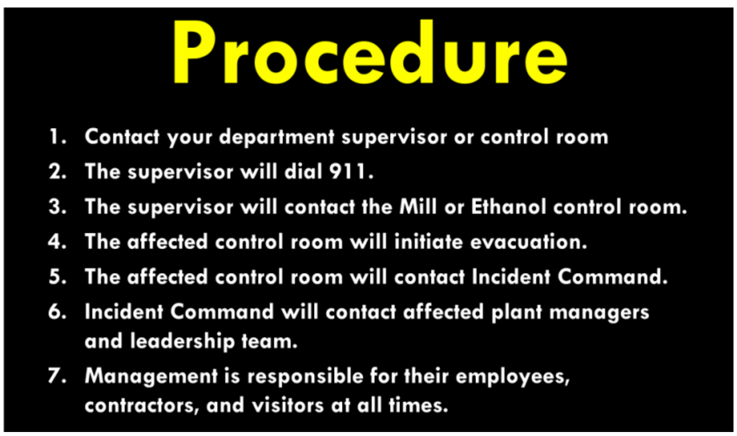

Figure 65: Excerpt of the Emergency Response Plan training. (Credit: Didion)

Although Didion's training covered evacuating the mill facility when a fire is detected, the practice outlined in the training was not performed on the night of the incident. While multiple employees were trying to identify the source of smoke within the mill, there was no indication that the employees planned to evacuate until the fire was observed. Not all employees were alerted to the potential fire within the milling process. The presence of smoke within the facility, without a discernable cause, was not recognized as the presence of a fire that required external assistance. Due to the deviation from the training and emergency response plan, the employees were placed in a hazardous situation by trying to identify the source of smoke rather than evacuating the facility, shutting down the equipment, and mitigating the incident.

The CSB concludes that Didion's practices during the incident did not match the policy or training for emergency response, such as evacuating the mill facility when smoke was observed. Had Didion contacted emergency responders, shut down the mill facility, and evacuated the mill when the smoke was first observed, the severity of the incident could have been greatly reduced.

As part of the emergency response plan, employees were allowed to fight incipient fires with fire extinguishers. Didion trained its employees on incipient-stage firefighting. Didion's training described an incipient stage fire as "a fire in the beginning stages which can be controlled with a portable fire extinguisher…" and that does not require personal protective equipment.

While Didion trained its employees to address a fire in the incipient stage, the identification of and response to such a fire could allow the fire to transition to a flash fire or explosion, which is what occurred during the incident. As with the incident on May 29, 2017, the smoldering fire that was initially treated with fire extinguishers rapidly transitioned to a larger fire that required fire department response. The incipient fire training does not mention combustible dust or the hazards posed by smoldering fires of combustible dust material within the confines of the process equipment.

The CSB concludes that Didion incorrectly treated fires in process equipment as incipient fires that could be treated with fire extinguishers, which caused the employees to attempt to locate the source of smoke rather than evacuate the facility prior to the escalation from the smoldering fire to explosions. Didion's incipient fire training program did not adequately inform employees of the potential hazards of the transition of incipient combustible dust fires to flash fires or explosions. Had Didion's training instructed employees to not fight unidentified fire inside process equipment, the employees could have shut down and evacuated the facility and prevented the injuries and fatalities that occurred due to the fires and explosions that occurred during the incident.

The CSB recommends that Didion update its incipient fire training program to not allow firefighting of fires in process equipment.

4.10.2 Industry Guidance on Emergency Preparedness

The 2017 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, provides guidance on emergency planning, response, and firefighting [6, p. 27]. The NFPA instructs that when fires are discovered, they should be promptly reported to management and emergency responders, including the fire department. Additionally, the NFPA cautions that, "[i]f a fire cannot be controlled promptly in its incipient stage, the endangered structure(s) shall be evacuated [6, p. 27]." The NFPA also requires that "[t]he emergency response plan shall be coordinated with local emergency responders and include fire department pre-fire plans [6, p. 27]."

The 2016 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, states "a written emergency response plan shall be developed for preparing for and responding to work-related emergencies including, but not limited to, fire and explosion." The standard further explains in the Explanatory Material Annex[a] that this requirement should incorporate the following elements:

- A signal or alarm system
- Identification of means of egress
- Minimization of effects on operating personnel and the community

[a] The Explanatory Material Annex is "…not a part of the requirements of [the] NFPA document but is included for informational purposes only [46]."

- Minimization of property and equipment losses
- Interdepartmental and interplant cooperation
- Cooperation of outside agencies [46, p. 57]

The annex also explains that "[e]mergency drills should be performed annually by plant personnel. … Disaster drills that simulate a major catastrophic situation should be undertaken periodically with the cooperation and participation of public fire, police, and other local community emergency units and nearby cooperating plants [46]."

The CSB concludes that the Didion emergency response plan did not incorporate guidance from the NFPA to provide procedural instructions on responding to upset conditions or when to trigger evacuations, such as when a fire cannot be promptly controlled. Had Didion provided followed guidance on emergency response practices, such as those in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Process Facilities*, the employees could have responded to the developing emergency and evacuated, which could have mitigated the severity of the incident.

The CSB recommends that Didion update the Emergency Response Plan to provide specific instructions for emergency response, firefighting, evacuations, and when to contact emergency responders, such as the guidance given by the 2020 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, and Chapter 8 of the 2019 Edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*.

The CSB recommends that Didion implement a facility-wide alarm system, in accordance with NFPA 652 (2016) Chapter 9 and provide training for the use of this system in place of verbal communications for evacuations.

4.10.3 OSHA Requirements on Emergency Preparedness

The OSHA *Grain Handling Facilities Standard* requires facilities to implement emergency action plans. These plans are subject to the requirements of 29 CFR § 1910.38, *Emergency Action Plans*. The Emergency Action Plans require employers to develop a written or oral plan based upon the number of employees at a facility. Didion was required to maintain written plans that addressed the response to emergency situations. The plans must include procedures for reporting fires or other emergencies, emergency evacuations, evacuation and exit routes, accounting for employees, and other requirements.

OSHA's Emergency Action Plan additionally requires employers to have and maintain employee alarm systems, which must meet the requirements of 29 CFR § 1910.165, *Employee Alarm Systems*. These systems are intended to provide warnings to employees to perform emergency actions or allow for enough time for employees to evacuate [72]. The *Employee Alarm Systems* standard requires that "[t]he employee alarm system shall provide warning for necessary emergency action as called for in the emergency action plan, or for reaction time for safe escape of employees from the workplace or the immediate work area, or both." On the night of the 2017 incident, Didion lacked an employee alarm system to trigger an emergency evacuation due to smoke and fire observed on 1B.

Furthermore, the *Employee Alarm Systems* standard requires, "[t]he employer shall establish procedures for sounding emergency alarms in the workplace. For those employers with 10 or fewer employees in a particular workplace, direct voice communication is an acceptable procedure for sounding the alarm provided all employees can hear the alarm [72]."

The lack of an employee alarm system further exacerbated the event severity because some employees were unaware of the ongoing fire and subsequent explosions until the situation had progressed to the point at which multiple explosions and building collapses were imminent.

The CSB concludes that Didion did not have a communication method to immediately notify all employees of upset conditions or emergency situations to trigger an evacuation, which likely contributed to the injuries and fatal injuries of non-essential employees who were not actively involved in troubleshooting. The reliance on radio communications delayed the potential employee evacuation prior to the incident.

Following the incident, OSHA cited Didion for failure to meet the requirements of the emergency action plan requirements of the *Grain Handling Facilities Standard.*

4.10.3.1 Post-Reconstruction Didion Emergency Preparedness

In addition to the gaps in the response that occurred during the May 31, 2017 incident, an incident occurred in 2019 that further highlights Didion's emergency response deficiencies. While operating the milling process, the millers began to smell smoke. Rather than immediately initiating an evacuation, the employees began to search for the source of the smoke. Upon notification of a fire, an employee proceeded to the location of the observed debris at the size reduction equipment. The plant shutdown was not initiated until 10–25 minutes after the first notification of fire over the radio. Although the evacuation was initiated, it took approximately 20–35 minutes to evacuate all of the employees and have them gather at the rally point.

As part of the investigation and response to the 2019 incident, Didion found multiple deficiencies. Didion determined the evacuations had not been drilled or practiced as part of the training program and the evacuation was not triggered per the policy. The evacuation was triggered using radios rather than the facility-wide fire alarm system.[a] Additionally, Didion determined that the process instrumentation and smoke detectors installed at that time did not sense the smoldering fire inside the equipment. The lack of adequate fire detection resulted in the employees searching for the source of the smoke, potentially placing the employees in a hazardous situation of locating a fire or smoldering material that could transition to a flash fire or explosion.

The CSB concludes that Didion's training program was inadequate to ensure the employees performed the tasks as directed by the training documentation. Rather, the mill facility's standard practice placed employees in potentially hazardous scenarios while trying to investigate potential sources of smoke or fire. Furthermore, the practice of employees identifying smoldering fires and fighting incipient fires, rather than evacuating, was a widespread practice that placed employees in potentially hazardous situations.

[a] The fire alarm system and employee alarm system was installed in the reconstructed mill facility in 2019. This alarm system did not exist in 2017.

The CSB recommends that Didion revise the emergency response plan to be in accordance with NFPA 61 (2020) Chapter 8.10 and 29 CFR § 1910.38, *Emergency Action Plans*, and ensure all employees are trained on the updated plan.

The CSB also recommends that Didion assess its pre-deflagration detection and suppression engineering controls for adequacy to detect and alert employees of the emergency situation, such as a smoldering fire, and trigger an evacuation.

4.11 Personal Protective Equipment

During the events that occurred on the night of May 31, 2017, many of the Didion employees were exposed to fire and heat due to the fires and explosions throughout the process. Several severe and fatal injuries that occurred on May 31, 2017, can be attributed to employees' exposure to the flames generated by the combustible dust explosions and flash fires. Many of the employees experienced burns on their arms, legs, and torsos. As described by one employee,

> [The fire] [b]lew a ring around almost all of us that were in the burn unit. There's a [burn] ring around all of us because when the explosion happened, it blew all of our shirts up.

As described in **Section 4.7** above, Didion experienced a flash fire in 2013 that resulted in an employee being engulfed in a fireball due to lofted dust that ignited. The incident investigation performed on the fire did not evaluate the need for fire-resistant clothing as a potential corrective action.

4.11.1 Didion Personal Protective Equipment

The Didion personal protective equipment (PPE) procedure, published in April 2014, established the use of safety glasses, hard hats, safety shoes, respirators, and hearing protection. Under the Good Manufacturing Practices (GMP) requirements[a] used at Didion, all employees working in the processing area were required to wear the uniforms provided. However, employees not supplied with uniforms were allowed to wear laundered street clothing. Using street clothes or polyester uniforms did not account for the potential hazards of combustible dust. Polyester and synthetic materials are not flame resistant and melt under high temperatures. Cotton clothing can provide minimal protection, but it is not flame-retardant without chemical treatment. Additionally, flame-resistant clothing is only resistant to short-duration flash fires. Flame-resistant garments cannot provide protection from a concentrated or sustained fire.

The CSB concludes that Didion did not require its employees to use flame-resistant garments for protection against potential thermal injuries from combustible dust flash fire events that contributed to the severity of the injuries in the incident.

[a] GMP are requirements are defined by the FDA under 21 CFR § 117 [93].

4.11.2 Guidance on Personal Protective Equipment

4.11.2.1 OSHA Guidance

OSHA covers the requirements of PPE under 1910 Subpart I, *Personal Protective Equipment*. Within Subpart I, 29 CFR § 1910.132, *General Requirements*, provides instructions to employers for assessing hazards and providing PPE to employees.

> Protective equipment, including personal protective equipment for eyes, face, head, and extremities, protective clothing, respiratory devices, and protective shields and barriers, shall be provided, used, and maintained in a sanitary and reliable condition wherever it is necessary by reason of hazards of processes or environment, chemical hazards, radiological hazards, or mechanical irritants encountered in a manner capable of causing injury or impairment in the function of any part of the body through absorption, inhalation or physical contact [73, p. 1].

The CSB concludes that Didion did not assess the milling processes for the hazard of flash fires and dust explosions either prior to the incidents that resulted in employee injuries, or after those incidents. Had Didion assessed and implemented personal protective equipment for potential flash fire hazards, the severity of the injuries could have been mitigated.

The OSHA *Grain Handling Facilities Standard* does not prescriptively address the use of or assessment for flame-resistant garments within the standard. Within Appendix A of the *Grain Handling Facilities Standard*, examples of training needed for covered facilities include the hazards of different types of PPE; however, the examples provided in the appendix are described as not the only way to comply with the standard.

In 1998, OSHA cautioned against the use of polyester uniforms for facilities governed under 29 CFR § 1910.272.

> …[T]he Grain Handling Facilities Standard, 29 CFR 1910.272 Appendix A, Section 3, Training, states that the types of work clothing should also be considered in the training program at least to caution against using polyester clothing that easily melts and increases the severity of burns, as compared to wool or fire-retardant cotton [74, p. 1].

Furthermore, OSHA instructs:

> …29 CFR 1910.132(d)(1) states the employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall: select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment [74, p. 2].

The CSB concludes that the lack of prescriptive requirements for the use or assessment for flame-resistant personal protective equipment (PPE) in grain handling facilities that present combustible dust hazards can result in underspecifying the PPE necessary to keep employees safe. Had the *Grain Handling Facilities Standard* required the use of flame-resistant PPE, Didion could have been required to

implement employee protections that could have prevented or mitigated the numerous burn injuries, including the injuries that resulted in hospitalizations.

The CSB recommends that OSHA develop a comprehensive combustible dust standard that requires the assessment of flame-resistant personal protective equipment for facilities that handle grain that can present a combustible dust hazard.

4.11.2.2 NFPA Guidance

In June 2016, the NFPA adopted the 2017 edition of NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*. This edition of NFPA 61 adopted the requirement for new and existing facilities to provide PPE in accordance with NFPA consensus standards. The NFPA provides two consensus standards regarding fire-retardant clothing, which were first issued in 2001. NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* covers the design, construction, and certification of flame-resistant garments. Additionally, the standard sets forth requirements for flame-resistant clothing with the intent of:

> …not contributing to the burn injury of the wearer, providing a degree of protection to the wearer, and reducing the severity of burn injuries resulting during egress from or accidental exposure to short-duration thermal exposure from fire [75].

NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Flash Fire*, covers the selection, use, and maintenance of flame-resistant clothing. The standard is intended to:

> …reduce the health and safety risks associated with the incorrect selection and use of flame-resistant garments and those risks associated with incorrectly maintained, contaminated, or damaged flame-resistant garments [76].

NFPA 2113 requires facilities to conduct hazard analyses of the working environment to determine the need for flame-resistant garments. The standard also requires the reassessment of hazards on a five-year basis or when significant changes are made to validate that the correct type of PPE is in use and that the requirements have not changed [76].

Key Lesson

To ensure that hazards are appropriately assessed, employers should consider abnormal and upset conditions when assessing personal protective equipment.

As defined by NFPA, Class II locations are defined as "… those that are hazardous because of the presence of combustible dust [77, p. 4] [78, p. 351]." Didion defined the milling operations as Class II, Div. 2, which, according to NFPA, is hazardous due to the presence of combustible dust and can present a flammable or explosible atmosphere during an upset condition. As there is no way to know when upset conditions can occur, using flame-resistant garments could have mitigated the potential exposure to a flash fire or flame front generated by the combustible dust at Didion.

Following the incident, the safety manager discussed the development of the assessments for PPE. Didion did not follow any of the published guidance for assessing the hazards that could require the use of flame-resistant garments. Didion could not locate any records of PPE assessments that had been performed for the milling operations. Based on the 2013 flash fire incident in which an employee was burned and the electrical classification of the processing area, Didion was aware of the potential for a flash fire that could occur in the milling operations due to the presence of combustible dust that could result in burn injuries to employees.

The CSB concludes that Didion did not appropriately address the hazard of flash fires and dust explosions in prior incidents that resulted in multiple employee injuries, including several hospitalizations due to the severity of the burns.

The CSB recommends that Didion perform PPE hazard assessments, such as those prescribed by NFPA 2113, and implement flame-resistant garments as deemed necessary from the analyses.

4.12 Process Safety Leadership

The CSB has assessed process safety leadership and process safety culture in several investigations, such as BP Texas City[a] and the Macondo Well Blowout.[b] Process safety is built upon a company's understanding of hazards and risks, management of risks, learning from prior experience, and commitment to process safety. One element necessary for a strong process safety culture is strong safety leadership, which includes visible, active, and consistent support for process safety programs at all levels of management within an organization [79, p. 46]. The CCPS further states:

> Leaders at any level of the organization must ensure that their employees, their contractors, and they themselves have the knowledge, skills, and resources they need to execute their process safety roles [80, p. 60].

There are a number of leadership attributes and principles that aid in the development of strong process safety culture. These attributes and principles include, but are not limited to:

1. Maintain a Sense of Vulnerability
2. Understand and Act Upon Hazards

[a] BP America (Texas City) Refinery Explosion | CSB Investigation
[b] Macondo Blowout and Explosion | CSB Investigation

3. Deference to Expertise
4. Combat Normalization of Deviance [80, p. 55]

While these attributes can point to a strong safety program and culture, the failure to effectively adopt these principles can indicate weak leadership and inadequate safety culture. Didion had numerous warnings of the hazards of combustible dusts (**Section 4.1** and **Section 4.9**) and had opportunities to prevent or mitigate these hazards (**Section 4.6** and **Section 4.7**) but failed to do so, which contributed to the incident and its severity.

4.12.1 Sense of Vulnerability

A sense of vulnerability is the appreciation of potential consequences from process safety incidents. The sense of vulnerability can be seen as the opposite of complacency and a false sense of security.

Gaps in the OSHA *Grain Handling Facilities Standard* underscore the need for facilities handling combustible dust to maintain a sense of vulnerability. In addition, the CCPS's *Process Safety – Leadership from the Boardroom to the Frontline* discusses the potential gaps in regulations and unregulated hazards.

> Regulations do not exist to control any single company's risk. At best they exist to control societal risk overall…. If you have unregulated hazards, your facility may be in complete compliance, but fail to manage those hazards sufficiently to meet your corporate risk criteria [80, p. 40].

Didion relied on its food safety programs to act as its combustible dust management system. As discussed in **Section 4.5**, the requirements of the food safety programs did not address the potential hazards presented by combustible dust in the facility, nor were these programs intended to address combustible dust hazards. Furthermore, after the incident, one member of Didion management told the CSB that they didn't believe that the explosion was caused by combustible dust.

> So I don't…I don't believe that this was a combustible dust explosion. I think something else happened. I mean we had a clean mill.

Additionally, one Didion manager stated, "Obviously, you know, I never had fear of an explosion occurring, because I didn't think it was that bad." Didion's reliance on housekeeping and food safety programs provided a false sense of security of the hazards presented by the combustible dust in the mill. Dating back to the 2010 OSHA inspection, OSHA noted:

> [Didion] stated that the dust was not combustible… Management stated [that] under certain conditions the powder may be combustible, and they knew corn was combustible.

Following the 2010 OSHA inspection and 2012 insurance inspection discussed in **Section 4.9**, the focus of the response efforts from Didion pointed to proving the particle sizes were too large or dilute to generate an explosive atmosphere. Didion's belief that the material was too large or dilute to be explosive meant that Didion did not consider the material to be a hazard and that an explosion could not occur within the facility despite evidence to the contrary.

The CSB concludes that Didion did not maintain a sense of vulnerability in its operations, resulting in the inaccurate belief that dust explosions could not occur at its facility, which allowed hazards to be underestimated, resulting in the incident and the lack of protections for the employees.

4.12.2 Understand and Act Upon Hazards

Company leaders must have a strong understanding of the processes to assess and act upon a hazard or risk to employees or others. To understand and act upon hazards, the employees and leaders must be aware of identified risks.

As discussed above in **Section 4.9,** many Didion leaders were unaware of the requirements under OSHA and NFPA for the management of combustible dust hazards. Furthermore, based on interviews with frontline workers and management, not all employees were aware of the potential hazards associated with combustible dust. In fact, the manager responsible for the audits of the housekeeping and food safety program implementation stated that they were unaware of the potential hazards.

> More the food safety, yes, because I don't personally remember getting much or having much knowledge on this dust explosion possibilities.

Additionally, the transfer of knowledge and the understanding of combustible dust hazards at Didion was inadequate. After the incident, one employee noted:

> I don't think management really told [the employees] prior. I know that there had been an environmental safety manager who had had some dust hazard analysis done, and I think there was some push back as far as [hazard] classification.

Following the 2010 OSHA inspection and the subsequent follow-up, Didion executive leadership stated that they should consider the installation of suppression cannons on the ducting to the Dry Grit Filter. The installation of any mitigative engineering controls, such as deflagration suppression, did not occur, allowing the propagation of fire to the Dry Grit Filter and back into the process on the night of the incident. Ultimately, Didion had calculations performed by a structural engineer to determine the potential concentration of combustible dust in process equipment. Didion chose to use the evaluation as the basis for not installing engineering controls that could have prevented or mitigated the May 31, 2017 incident.

The CSB concludes that while some of Didion's leadership may have recognized the hazards of combustible dust within the facility, the failure to communicate the hazards, act upon the hazards, and mitigate risk resulted in the inadequate engineering and administrative controls to prevent the dust explosion.

4.12.3 Deference to Expertise

Deferring to expertise "allows key decisions to be made, naturally and by design, by the proper people based on their knowledge and expertise, rather than their rank or position [80, p. 78]." There are multiple examples of Didion's failure to defer to others with combustible dust expertise.

OSHA and Insurance Inspections

As discussed in **Section 4.9**, Didion owners and executive leadership received multiple warnings of the potential hazards of combustible dust. However, Didion's responses to recommendations and Didion's reliance on the calculations showed that Didion did not reconsider or defer to the expertise of external inspectors and auditors.

Dryer and Dust Collector Equipment Design

During the design of the equipment involved in the fire on May 29, 2017 (**Section 4.7.2**), Didion's insurance company raised the need for the dry and dust collection equipment to meet the NFPA codes for fire suppression systems. In response, an executive leader stated, "Only if it is not costly and adds value. I would not worry about it." The employee working on the project followed up with their plan to proceed: "I will plan on getting a quote for the filter and then [executive leadership] can decide if it's worth proceeding with." Ultimately, this equipment was severely damaged on May 29, 2017, when a burning ember reached the baghouse, which had been identified as needing fire suppression systems.

Mill Reconstruction Activities

Following the May 31, 2017 incident, during the design of the reconstructed facility, the project team communicated with executive leadership about the planned engineering controls, administrative controls, and the cost to the business. Below is an excerpt of Didion leadership's comments:

> We realize that we have a business to run and that defaulting to costly engineering controls is not the only answer or strategy. In order to have a strong safety culture, we need to encourage strong behaviors and awareness and ensure that we as a leadership group are modeling good safety behaviors ..... consistently. We need to make safety a part of every job we do. We agree that there are times when engineering controls are the best path to eliminate risk but also appreciate that operating and maintenance procedures also carry an important role and should be a part of our recommendations as well.

While there are indications that some engineering controls were installed in the new facility, the gaps identified by Didion's combustible dust expert during the DHAs (**Section 4.2**) indicated that not all necessary controls were implemented prior to the completion of construction. Furthermore, the decision to not implement identified engineering controls did not follow the concepts of inherently safer design concepts, opting to implement administrative controls instead of engineering controls that could more effectively prevent or mitigate risk due to combustible dust hazards.

The CSB concludes that Didion did not utilize or defer to expertise prior to the incident regarding the hazards of combustible dust within the process. Didion utilized cost as the basis for the installation of engineering controls rather than the potential consequences of hazards and the expertise of others more familiar with combustible dust.

4.12.4 COMBAT NORMALIZATION OF DEVIANCE

Normalization of deviance is a term used to describe the gradual erosion of standards because of increased tolerance of nonconformances [80, p. 79]. As evident in the multiple smoldering fires and process upsets in the five years prior to the incident (**Section 4.7**), Didion normalized the occurrence of smoldering fires and other upset conditions inside the process equipment that could result in flash fires or dust explosions. Didion did not learn from the near-miss incidents prior to the explosion. The tendency of management and leadership to accept fires and near-miss smoldering events inside process equipment as normalized deviations, in addition to failing to learn from these incidents, likely conditioned the Didion employees to not recognize the emergency nature of the events on the night of the incident.

The CSB concludes that Didion normalized deviance regarding smoldering fires, which caused employees to not recognize the significance of fire inside the process equipment and the potential for it to transition to catastrophic dust explosions.

4.12.5 SUMMARY OF LEADERSHIP DEFICIENCIES

Due to the number of weaknesses in the implementation and management of safety programs, Didion exhibited a lack of safety leadership and a poor safety culture.

The CSB concludes that prior to the incident, Didion had a poor safety culture and weak safety programs due to inadequate process safety leadership. The lack of a sense of vulnerability, the lack of understanding and acting upon hazards, the failure to defer to expertise, and the normalization of deviance resulted in the inadequate response to industry-recognized combustible dust hazards, allowing the injuries and fatalities to occur when the dust explosions occurred, and the buildings collapsed.

The CSB recommends that Didion develop and implement a process safety leadership and culture program, based on the guidance of the CCPS's *Guidelines for Auditing Process Safety Management Systems* and *Process Safety: Leadership from the Boardroom to the Frontline*. The program should include:

a. Development of a process safety policy;
b. Development of a process safety leadership and culture committee;
c. Development of appropriate goals for process safety;
d. A commitment to process safety culture;
e. Development of leading and lagging process safety metrics;
f. Process Safety Culture Assessments; and
g. Engagement with external process safety leadership and culture experts

The CSB recommends that Didion develop a comprehensive combustible dust process safety management system, such as OSHA's *Process Safety Management* standard or the requirements in NFPA 652 (2019) Chapter 8, which incorporates:

a. Management of Change for combustible dust;
b. Process safety information management;
c. Management of audits and inspections;
d. Fugitive dust management;

e. **Incident investigation;**
f. **Dust Hazard Analyses;**
g. **Management of engineering controls for combustible dust; and**
h. **Emergency preparedness.**

4.13 Regulatory Coverage of Combustible Dust

Following a 2013 OSHA inspection, OSHA warned Didion of the potential for the propagation of explosions through the interconnected dust collection systems at Didion:

> The explosion protection provided for the [Dry Grit Filter] did not include elements of deflagration isolation protection to prevent a potential deflagration occurring within the collector from returning back into the facility and upstream processes through the 'dirty air' ducting.

In 2013, OSHA did not cite any deficiencies regarding the *Grain Handling Facilities Standard*. Additionally, OSHA did not issue a citation for the follow-up inspection and stated, "…no OSHA standard applies and it is not considered appropriate at this time to invoke Section 5(a)(1), the General Duty Clause of the Occupational Safety and Health Act." In order to cite the General Duty Clause, several criteria must be met to be used for a citation, including:

1. No standard for the hazard must exist;
2. The citation cannot impose a stricter requirement than imposed by an OSHA standard; and
3. The citation cannot be used to require additional abatement methods not existing in a standard.

While the *Grain Handling Facilities Standard* covers some aspects of deflagration control, as discussed above in **Section 4.3**, the standard does not incorporate requirements recommended as abatement at Didion, such as deflagration isolation and hazard analysis. Thus, a citation would impose stricter requirements than the existing OSHA standard. Furthermore, in 2013, NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, did not require isolation engineering controls. Instead, OSHA recommended voluntary actions by issuing a HAL, which recommended Didion mitigate the potential explosion hazards using NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 69, *Standard on Explosion Prevention Systems*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*.

The CSB concludes that the OSHA *Grain Handling Facilities Standard* did not confer adequate regulatory requirements to assess and abate potential combustible dust hazards, such as those present at Didion before the incident. Had Didion been required to implement the engineering controls, such as deflagration isolation, the incident severity could have been mitigated.

As discussed in the OSHA Field Operations Manual, there was no framework for following up on HALs when no other citations were issued. OSHA could not follow up on the voluntary recommendations made to Didion following the 2013 inspection and HAL before the 2017 incident.

The CSB concludes that there is no mechanism or framework for follow-up inspections when issuing a Hazard Alert Letter (HAL). Had Didion been required to implement additional engineering controls, such as those identified in the HAL, Didion might have improved its deflagration isolation controls, which could have limited the spread of the fires and explosions and reduced the severity of the incident.

The CSB recommends that OSHA develop a program to trigger follow-up inspections when Hazard Alert Letters are issued for combustible dust hazards and there is insufficient evidence to demonstrate that those hazards have been abated.

Key Lesson

Safety regulations do not guarantee the safety of a process. Rather, regulations are the minimum threshold for maintaining safe operations. Largely unregulated hazards, such as combustible dust hazards, can exist in an otherwise regulated process. These hazards must be controlled beyond the existing regulatory requirements through the adoption of current industry standards and through the development of new regulations to prevent safety incidents.

At the time of the incident, combustible dust and the associated hazards were covered under various regulatory frameworks, but these safety management system frameworks contained — and still contain — gaps that prevent adequate management of combustible dust hazards.

OSHA lists the following standards as part of the OSHA combustible dust special industries: 29 CFR § 1910.261, *Pulp, Paper, and Paperboard Mills*; 29 CFR § 1910.263, *Bakery Equipment*; 29 CFR § 1910.265, *Sawmills*; 29 CFR § 1910.269, *Electric Power Generation, Transmission, and Distribution*, and 29 CFR § 1910.272, *Grain Handling Facilities.* Although these standards provide requirements for specific industries related to combustible dust, there is no overarching combustible dust standard that requires or addresses safety in general industry.

Since 2003, the CSB has investigated several combustible dust incidents and has made multiple recommendations for additional regulatory guidance for industries processing and handling combustible dust. In November 2006, the CSB published the *Combustible Dust Hazard Study*. In that study, the CSB examined process safety of combustible dust in the United States in general industry. The CSB concluded that "… combustible dust explosions are a serious hazard in American industry, and that existing efforts inadequately address this hazard [81]." As a result of the study, the CSB recommended that OSHA:

> Issue a standard designed to prevent combustible dust fires and explosions in general industry. Base the standard on current National Fire Protection Association (NFPA) dust explosion standards (including NFPA 654 and NFPA 484), and include at least - hazard assessment, - engineering controls, - housekeeping, - building design, - explosion protection, - operating procedures, and - worker training. [81]

This recommendation was reissued in the CSB's 2008 Imperial Sugar investigation and 2011 Hoeganaes Corporation investigation. Additionally, the CSB recommended that OSHA ensure that metal dusts were included in the combustible dust standard following the 2011 Hoeganaes Corporation investigation.

In 2007, OSHA published the Combustible Dust National Emphasis Program (NEP), which contained "…policies and procedures for inspecting workplaces that create and handle combustible dusts [82]." In 2008, the recommendation was reiterated following the Imperial Sugar explosion and CSB investigation. In 2009, OSHA began the rulemaking process for a combustible dust standard, but OSHA withdrew its rulemaking proposal in March 2017 [83].[a] OSHA published a revised NEP in January 2023. **Figure 66** shows the timeline of regulatory efforts for combustible dust.

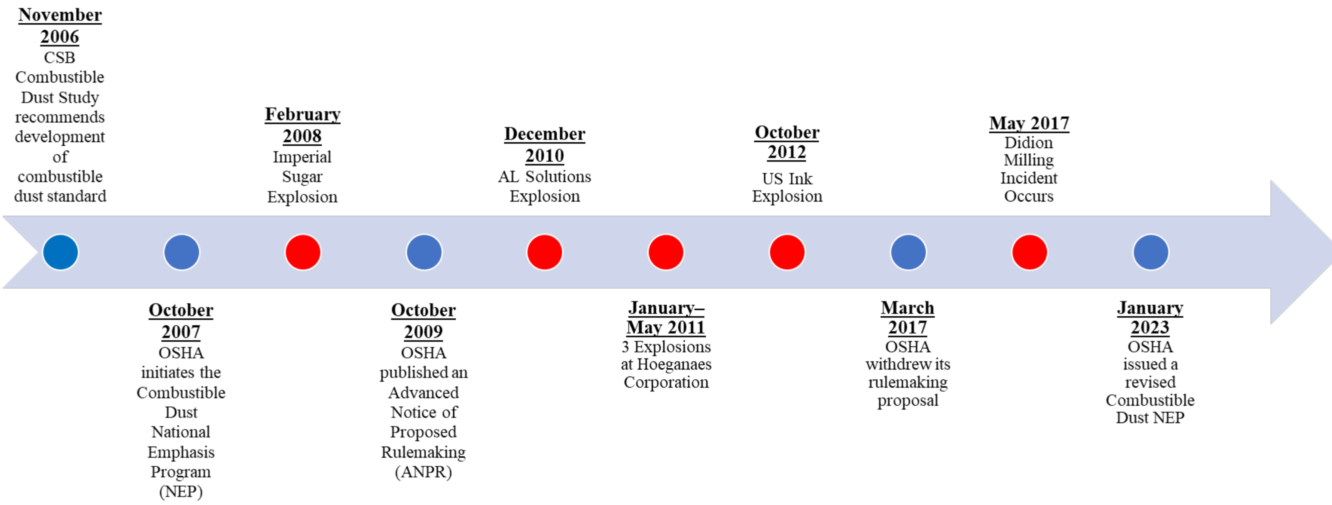

Figure 66: Timeline of CSB dust investigations and OSHA rulemaking efforts. The red dots indicate incidents, and the blue dots indicate actions by OSHA and CSB. (Credit: CSB)

The CSB has investigated several combustible dust incidents since 2003. The Combustible Dust Hazard Study was published in 2006. At the time of this report, the CSB has investigated eight incidents involving combustible dust that are not covered by the OSHA PSM regulations. Those incidents, which resulted in 40 fatalities and 136 injuries, are listed in **Table 9**.

[a] Combustible Dust Timeline

Table 9: Investigations completed by CSB involving combustible dust. (Credit: CSB)

Incident Date	Investigation Description	Dust(s) Involved	Severity
January 29, 2003	West Pharmaceutical[a]	Polyethylene	5 fatalities 38 injured
February 20, 2003	CTA Acoustics[b]	Phenolic Resin	7 fatalities 37 injured
October 29, 2003	Hayes Lemmerz[c]	Aluminum	1 fatality 2 injured
Combustible Dust Hazard Study[d] Published			
February 7, 2008	Imperial Sugar dust explosion and fire[e]	Sugar	14 fatalities 38 injured
December 9, 2010	AL Solutions dust explosion [f]	Titanium	3 fatalities
January 31, 2011	Hoeganaes Corporation dust flash fires[g]	Powdered Iron	5 fatalities
October 9, 2012	US Ink dust explosion and fire[h]	Powdered Ink	7 injured
May 31, 2017	Didion Milling dust explosions	Corn	5 fatalities 14 injured

A CSB report published in 2018, *Call to Action on Combustible Dust Hazards*, [i] assessed the number of combustible dust incidents that occurred in an 11-year period from 2006 through 2017. The incidents reviewed in that report were compiled from the incident screening data. Although the report did not utilize all potential data sets or present an exhaustive list of incidents, the data indicated that several industries experienced combustible dust incidents, including food products, metal industries, and wood products.

Dust Safety Science began compiling data on combustible dust incidents in 2016 [84]. **Figure 67** shows the overall United States trend of combustible dust events by industry that occurred from 2017-2021, as reported by Dust Safety Science. As the data show, the agricultural and food processing industries represent the greatest number and highest percentage of combustible dust incidents, followed by the wood processing industry.

[a] West Pharmaceutical Services Dust Explosion and Fire | CSB Investigation
[b] CTA Acoustics Dust Explosion and Fire | CSB Investigation
[c] Hayes Lemmerz Dust Explosions and Fire | CSB Investigation
[d] Combustible Dust Hazard Study | CSB Investigation
[e] Imperial Sugar Company Dust Explosion and Fire | CSB Investigation
[f] AL Solutions Fatal Dust Explosion | CSB Investigation
[g] Hoeganaes Corporation Fatal Flash Fires | CSB Investigation
[h] US Ink Fire | CSB Investigation
[i] Call to Action | CSB

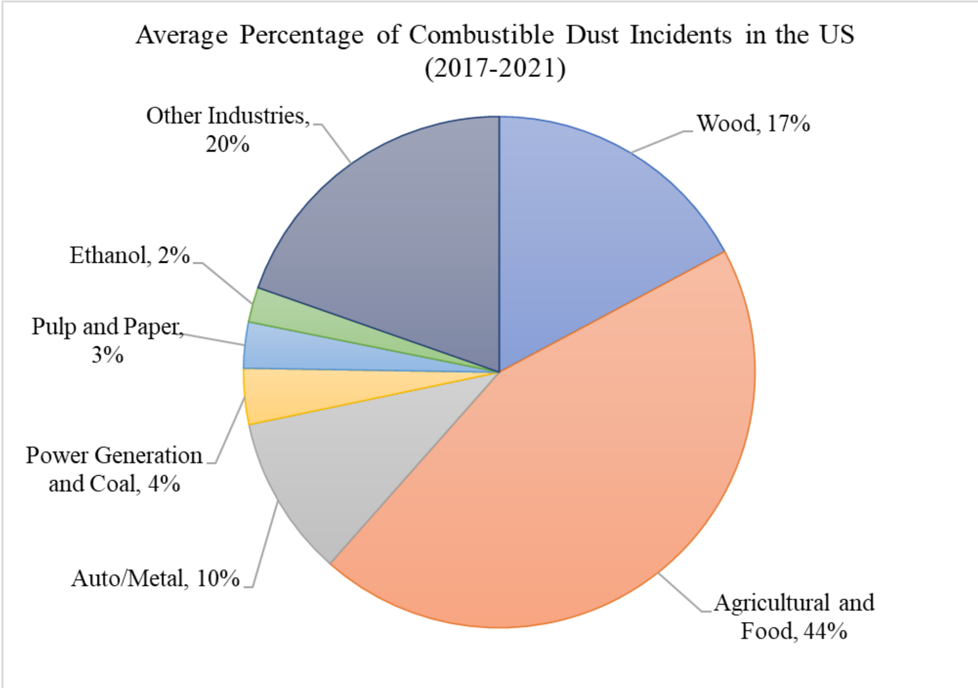

Figure 67: Summary of combustible dust incidents in the U.S. by industry. (Credit: Dust Safety Science [85])

Table 10 summarizes the combustible dust incidents that occurred in the U.S. from 2017 to 2021 based on the number of total incidents, fires, explosions, injuries, and fatal injuries per year.

Table 10: Summary of recent combustible dust incidents in the U.S. (Credit: Dust Safety Science [85])

	# of Incidents	# of Fires	# of Explosions	# of Injuries	# of Fatalities
2017	145	117	28	52	6
2018	194	158	36	39	1
2019	213	176	37	42	1
2020	143	117	26	35	1
2021	118	98	20	26	2
Totals	813	666	147	194	11

While there are some commodity-specific OSHA standards[a] for combustible dust, these standards do not fully address the scope of modern process safety management systems, such as the requirements in OSHA's 29 CFR § 1910.119, *Process Safety Management of Highly Hazardous Chemicals* Standard.

The NFPA commodity-specific standards do incorporate requirements for safety management systems, and unless they are adopted by legislative code, the requirements are not required regulatorily. These standards can be enforced through the General Duty Clause, but that does not always happen, which can leave gaps in the regulatory coverage for combustible dust hazards.

[a] OSHA lists the following standards as part of the OSHA combustible dust special industries: 29 CFR § 1910.261, *Pulp, paper, and paperboard mills*, 29 CFR § 1910.263, *Bakery equipment*, 29 CFR § 1910.265, *Sawmills*, 29 CFR § 1910.269, *Electric Power Generation, Transmission, and Distribution*, and 29 CFR § 1910.272, *Grain handling facilities.*

As shown throughout this report and in prior CSB combustible dust investigations, the use of a safety management system can mitigate or prevent incidents. A good framework is the OSHA PSM requirements. The interconnected nature of combustible dust catastrophes and the elements of the OSHA PSM standard highlights the need for more stringent safety requirements due to the number and potential severity of these incidents. Of the combustible dust incidents that the CSB has investigated, only one company (Hoeganaes Corporation) was required to meet the PSM standard due to the company's use of hydrogen in its process.

Table 11 highlights the PSM elements that were identified in the current and previous CSB investigations.

Table 11: PSM elements referenced in prior CSB combustible dust investigations. (Credit: CSB)

PSM Element	CSB Reports Referencing PSM Elements
Process Safety Information	• **Didion Milling** • Imperial Sugar
Process Hazard Analysis	• **Didion Milling** • US Ink • Hoeganaes
Operating Procedures	• CTA Acoustics • Hayes Lemmerz • **Didion Milling**
Employee Participation	• N/A
Training	• **Didion Milling** • Hayes Lemmerz • Imperial Sugar • Hoeganaes
Contractors	• US Ink • West Pharmaceutical
Pre-Startup Safety Review	• N/A
Mechanical Integrity	• Hoeganaes Corporation
Hot Work Permit	• N/A
Management of Change	• **Didion Milling** • Hayes-Lemmerz • US Ink
Incident Investigation	• **Didion Milling** • CTA Acoustics • US Ink
Emergency Planning and Response	• **Didion Milling** • CTA Acoustics • Imperial Sugar • US Ink
Compliance Audits	• **Didion Milling**
Trade Secrets	• N/A

OSHA revised and reissued the Combustible Dust NEP in January 2023. In the NEP summary, OSHA noted:

> In fiscal years 2013 to 2017, OSHA conducted 2,553 combustible dust inspections – 910 programmed[a] inspections and 1,253 un-programmed[b] inspections. During this period, the agency found 3,389 combustible dust violations—1,022 from programmed inspections and 2,367 from un-programmed inspections [86].

While these inspections have identified violations of existing OSHA standards, these inspections do not necessarily find gaps with safety management systems that are not included in the existing standards. The number of continued incidents related to combustible dust, as shown in **Figure 67** and **Table 10**, have remained elevated in food and agriculture industries.

The data show that many catastrophic combustible dust incidents might have been prevented had process safety management principles been applied. The potential for a combustible dust event to transition to a high-severity incident warrants further regulation and safety controls. To mitigate future catastrophic events, a focus on improving the overall performance of non-PSM-covered industries is necessary to reduce the rate of combustible dust incidents.

The CSB concludes that the insufficient regulatory oversight of processes and facilities that handle combustible dust contributed to the incident at Didion. The CSB also concludes that the OSHA Combustible Dust National Emphasis Program does not adequately assess for factors that can result in combustible dust fires and explosions that result in serious injuries and fatalities, such as deflagration isolation controls.

The CSB has determined that the recommendation to OSHA should be updated. While the CSB previously recommended the development of a combustible dust standard, the prior recommendation to OSHA only included some recommended management systems, such as: hazard assessment, engineering controls, housekeeping, building design, operating procedures, and employee training. As discussed in this section, the CSB identified additional management systems critical to managing combustible dust hazards. These management systems include hazard recognition, management of change, incident investigations, process safety information management, audit and inspection management, and emergency preparedness.

Therefore, the CSB supersedes recommendation **2006-1-H-1** to OSHA, originally published in CSB's 2006 Combustible Dust Hazard Study and reiterated in the 2008 Imperial Sugar, **2008-05-I-GA-R11**, and the Hoeganaes Corporation investigations, **2011-04-I-TN-R2**. Furthermore, the CSB supersedes the 2011 Hoeganaes Corporation recommendation, **2011-4-I-TN-1**, for the inclusion of metal dust into the combustible dust standard.

The CSB recommends that OSHA issue a standard for all industries that handle combustible dust, which should be based on the requirements of current and subsequent NFPA standards, including NFPA 61, NFPA 484, NFPA 652, NFPA 654, NFPA 655, and NFPA 664. The standard should include:

a. **Dust hazard analysis**
b. **Management of change**
c. **Incident investigation**

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[a] Programmed inspections are scheduled inspections based on criteria, such as national or regional emphasis programs [95].

[b] Unprogrammed inspections are triggered in response to alleged hazardous working conditions, fatalities, and complaints [95].

d. Engineering controls
e. Building design
f. Fugitive dust management
g. Operating procedures
h. Process safety information
i. External audit management
j. Training
k. Emergency response
l. Personal Protective Equipment

The CSB also recommends that, following implementation of a comprehensive combustible dust standard, OSHA update the *Grain Handling Facilities Standard* to clarify grain handling facilities with combustible dust are covered by the new Combustible Dust Standard.

5 Conclusions

5.1 Findings

Technical Analysis

1. Although the precise location could not be determined, a smoldering nest likely developed in equipment downstream of the Bauermeister gap mills in 1B, and likely initiated the incident.
2. Either an oscillating flame front or a series of small explosions spread burning material throughout the Bran process piping on 1B and accelerated a localized smoldering nest into a deflagration.
3. An explosion downstream of the South Gap Mill in 1B occurred, which propagated through the North and South BM Cyclones and continued to propagate throughout the connected process.
4. The deflagration that began in 1B propagated to the Dry Grit Filter.
5. A deflagration in the Dry Grit Filter propagated to other previously uninvolved parts of Didion's processes, which allowed explosions and fire to continue to spread throughout the mill processes.
6. The primary explosion in 1B and the ensuing propagations lofted fugitive dust and spread secondary explosions throughout the mill facility.
7. Secondary explosions contributed to the incident, and secondary explosions were necessary to produce some of the damage observed after the incident.
8. A primary explosion inside process equipment located in 1B initiated a secondary explosion inside the building on 1B. The primary explosion inside the equipment propagated through other connected equipment, and the secondary explosion propagated through the connected air supply shafts and other openings to cause fire and structural damage to equipment and buildings in areas not associated with the equipment in 1B.
9. Didion's add-on building design employing shared walls between connected mill buildings caused multiple buildings to collapse and significant structural damage throughout the mill facility, which caused multiple fatalities and injuries to employees.

Process Hazard Recognition

1. Didion did not accurately assess the number of process streams in the mill buildings that contained combustible dust. Didion did not fully recognize the combustible dust hazards of its materials, resulting in a lack of combustible dust safeguards, which directly led to the incident.
2. Didion did not recognize the propagation hazard that interconnecting numerous pieces of equipment presented and did not take sufficient action to prevent flame front propagation through its dust collection systems. This lack of recognition increased the likelihood that a propagation event could occur and allowed what could have been a localized fire and dust explosion to propagate throughout the facility.
3. Had Didion limited the equipment interconnectivity through its dust collection systems, the initial deflagration on 1B could not have propagated throughout the process equipment so easily, which could have reduced the severity of this event.
4. Didion's dust collector calculations were incorrect and that the Dry Grit Filter did contain an explosive dust concentration on the night of the incident, as evidenced by the Dry Grit Filter explosion. Had Didion acted upon this hazard, the incident consequences could have been reduced.

5. Didion's incorrect calculations contributed to the lack of recognition that most dust collectors, by their nature, contain an explosive dust concentration. Had Didion acted upon this hazard, the incident consequences could have been reduced.
6. Didion did not follow industry guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, or NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, in designing pneumatic transport or dust collection system ductwork and did not ensure adequate transport velocity throughout the facility. This unrecognized hazard likely resulted in significant combustible material deposits inside ductwork systems and potentially contributed to flame front propagations throughout the process ductwork during the incident.
7. Didion did not follow industry guidance such as NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids*, or NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, when making modifications to pneumatic transport or dust collection system ductwork and did not ensure adequate transport velocity throughout the facility. This unrecognized hazard resulted in significant combustible material deposits inside ductwork systems and contributed to deflagration propagations throughout the process ductwork during the incident.
8. Despite guidance to the contrary, Didion had no cleaning or inspection program to remove combustible dust accumulations from dust collectors or pneumatic conveying systems. As a result, significant combustible dust deposits inside ductwork were present on the night of the incident. This allowed a localized process fire to propagate throughout the mill buildings and processes the night of the incident.
9. The OSHA *Grain Handling Facilities Standard* does not address the process design considerations that could mitigate combustible dust hazards, such as those that resulted in the fires and propagations during the Didion incident.

Dust Hazard Analysis

1. Didion's delayed implementation of Dust Hazard Analyses (DHAs) prevented the assessment of the mill processes for potential combustible dust hazards in a timely manner and implementation of safeguards that could have prevented or mitigated the severity of the incident.
2. NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, does not cover all equipment that could have the potential for combustible dust hazards. As a result, hazards presented by the uncovered equipment could go unassessed. Had Didion been required to assess all of the process equipment, including the cyclones, pneumatic conveying systems, and rotary valves, as required by NFPA 652, *Standard on the Fundamentals of Combustible Dust*, Didion could have identified potential smoldering fire and explosion hazards in the equipment where the smoldering fire and first explosion likely occurred.
3. While Didion performed dust hazard analyses on the reconstructed mill, Didion did not implement deflagration controls that could have prevented the 2017 incident. The analysis performed by Didion contained potential gaps in the reconstructed facility that do not comply with the NFPA requirements for deflagration engineering protections and controls, which would not prevent the reoccurrence of an incident, such as the one in 2017.

Engineering Controls for Combustible Dust Hazards

1. Had Didion employed the use of optical or thermal detection safety systems within the ducting or process equipment, the initial ignition source could have been detected quicker and more accurately to allow the smolder fire to be addressed and could have prevented the incident.
2. The lack of deflagration isolation engineering controls allowed the flame front to propagate from the initial fire location throughout the mill facility via the interconnected systems, contributing to the widespread damage in the mill.
3. Had Didion employed the use of deflagration suppression systems, in conjunction with isolation engineering controls, the initial deflagration event could have been limited to the equipment and ducting around the ignition site. Had the propagation been halted, the incident could have been mitigated and could have prevented the subsequent explosions, structural collapses, and injuries and fatalities.
4. Didion did not have adequate deflagration venting systems to prevent equipment rupture that experienced overpressure, such as the South BM Cyclone and dust collector ducting. Had Didion properly implemented deflagration venting systems, some of the significant property damage could have been prevented, reducing the severity of the incident.
5. A deflagration vent on the dust collection equipment opened during the incident and directed flames at an evacuating employee who sustained significant burn injuries. Had the vent been installed to prevent exposure to employees, as required by NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, the burn injury could have been prevented.
6. Didion did not adequately design its dust collection system ducting to withstand deflagration pressures, nor did it provide adequate deflagration venting or isolation, resulting in the rupture of ducting, which allowed deflagrations to propagate outside of the process equipment.
7. Didion did not provide explosion protection in accordance with the OSHA *Grain Handling Facilities Standard* by not installing venting that directed outside of the building or implementing explosion suppression systems on the dust collection systems. Had Didion installed explosion protections, as prescribed by the *Grain Handling Facilities Standard*, the severity of the incident could have been mitigated through the use of explosion suppression systems or deflagration venting.
8. The OSHA *Grain Handling Facilities Standard* does not adequately provide direction for the inclusion of engineering controls, such as deflagration detection, isolation, or containment, that could prevent the propagation of fire or explosions through process equipment. Had Didion been required to implement deflagration engineering controls, such as detection or isolation, the incident could have been limited to the initial fire and explosion but not allowed to propagate and cause more widespread damage and injuries to employees.
9. The OSHA *Grain Handling Facilities Standard* does not address the deflagration venting requirements of air-material separators, such as cyclones, that could present the same hazard as dust collectors.

Structural Design for Combustible Dust Hazards

1. Didion either did not consider potential dust explosion hazards during the design and construction of the mill facility buildings or did not implement engineering controls for such hazards.
2. Didion did not design the mill buildings to withstand overpressure events, construct its mill buildings in accordance with industry guidance to mitigate the damage during a combustible dust explosion, or install deflagration venting on the mill buildings to relieve excessive pressure from secondary explosions. Had Didion constructed the buildings in accordance with this guidance, the extensive damage and collapse of mill buildings could have been prevented.
3. The lack of deflagration venting for the facility structures likely contributed to the building collapses due to the combustible dust explosions. Had Didion installed deflagration venting as part of the building

design, the building pressure could have been relieved, mitigating the damage to the buildings, and potentially preventing the collapse of the mill buildings.

4. The CSB concludes that prior to the incident, the Wisconsin Administrative Code had not adopted requirements to mitigate combustible dust hazards, such as those prescribed by Chapter 13 of the International Fire Code. These requirements could have compelled Didion to implement a building design to mitigate the combustible dust explosion hazards present during the incident that resulted in building collapse and serious and fatal injuries to Didion employees.
5. Following the 2017 incident, Didion assessed the combustible dust to incorporate into the structural design of the reconstructed facility. While Didion assessed the material for combustibility, Didion did not assess the dust for a worst-case scenario according to ASTM standards, which could result in building collapse and significant injuries. The lack of structural design considering worst case combustible dust hazards would not prevent a re-occurrence of structural collapse like the failures during the 2017 incident.

Fugitive Dust Management

1. Didion's Master Sanitation Schedule did not adequately identify or require maintenance of all areas at the facility to minimize the hazard of fugitive combustible dust accumulations.
2. Didion's purported use of the HACCP Plan for identifying and mitigating combustible dust hazards was ineffective, as food safety programs are not intended to evaluate worker or process safety.
3. Didion's Monthly Sanitation Inspection had ineffective housekeeping practices to fully address fugitive combustible dust hazards and allowed unacceptable levels of combustible dust to accumulate in some areas without triggering action either to prevent combustible dust accumulation through leak prevention or altering the cleaning schedule to clean more frequently, contributing to the severity of this incident. As a result, secondary dust explosions fueled by fugitive dust led to building collapse and multiple injuries and fatalities.
4. Had Didion implemented an effective fugitive combustible dust management program in accordance with NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, guidance, it could have reduced the severity of or eliminated secondary explosions.
5. OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272 does not include effective combustible dust housekeeping guidance included in current NFPA combustible dust standards, such as maintaining a dust cleaning threshold level, applying the threshold over a limited area, removing dust concurrently with operations, addressing local spills or transient releases promptly, providing for unscheduled housekeeping, or emphasis on cleaning overhead or hidden areas. This guidance could have strengthened Didion's fugitive dust management program, potentially reducing the severity or preventing secondary explosions.
6. OSHA's *Grain Handling Facilities Standard*, 29 CFR § 1910.272 does not adequately regulate combustible dust hazards. Deficiencies include:
   a. Only requiring grain elevators to maintain a maximum dust layer of 1/8-inch but not applying this standard to any other grain-handling facilities;
   b. Designating priority areas that do not include areas known to have caused significant explosions in the past, such as hidden or overhead areas like suspended ceilings or the air shafts at Didion;
   c. Allowing product spills to be treated differently from fugitive dust accumulations regardless of the hazard these spills might present; and

d. Allowing a dust layer over 100% of a room's area, rather than restricting allowable accumulation areas to a smaller size.

Management of Change

1. Didion did not adequately assess the temporary change of using a single blower system to transport material from two cyclones and the consequences of increasing solid material loading on the Bran process. Increasing solid material loading without increasing transport air flow can produce deposits, which created a situation favorable to harboring a smoldering nest downstream of the South BM.
2. The temporary change made the day of the incident that connected the two gap mills' transfer systems together likely contributed to the incident in part by confounding the operators' search for the smoldering material when they were unaware the two mills' discharges were tied together.
3. While food safety and quality may be incorporated into a Management of Change (MOC) program, Didion's MOC program did not effectively address known combustible dust hazards and was insufficiently designed to identify or address them. This likely contributed to the incident by allowing a temporary MOC to be installed without consideration of the potential consequences of that change. Didion's program lacked sufficient checks to ensure that safety hazards were appropriately and completely assessed, changes were designed and reviewed by qualified and trained personnel, and quality work was performed in compliance with the MOC program.
4. Didion's MOC procedure was not conducive to detecting or mitigating pneumatic conveying or dust collector hazards, or material accumulation inside ductwork, which are significant and well-recognized combustible dust hazards. Failure to account for these hazards when implementing changes in the mill facility allowed combustible dust to accumulate in multiple ductwork systems, among other things, contributing to the incident's severity.
5. Didion's MOC program did not apply appropriate technical rigor for the MOC review process, and as a result, did not effectively address known combustible dust hazards. This likely contributed to the incident by allowing a temporary MOC to be installed without consideration for the potential consequences of that change, and by allowing combustible dust to accumulate in multiple ductwork systems, contributing to the incident's severity.
6. NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, contains fewer MOC requirements than NFPA 652, *Standard on the Fundamentals of Combustible Dust*, such as addressing temporary changes, operating and maintenance procedures, employee training, and dust testing results, among other things. NFPA 61 also lacks general guidance, such as when to apply MOC, that NFPA 652 provides. These differences between the standards result in a less comprehensive and less effective MOC system in agricultural dust settings than in other industries, which are held to a higher standard in NFPA 652. Even if Didion had followed NFPA 61, it would have allowed the temporary MOC downstream of the North and South BMs to be implemented without a basis for the change, without full consideration of the safety and health implications, and without authorization by a knowledgeable, qualified reviewer. Had Didion's MOC program been required to more thoroughly define the basis and safety and health implications, and have changes reviewed by a knowledgeable, qualified reviewer, the incident might have been prevented or mitigated.
7. While Didion's MOC program may have complied with NFPA 61 as it existed at the time of the incident, the program could be strengthened by incorporating NFPA 652 requirements and guidance, such as modifications to operating or maintenance procedures, maintaining and evaluating the ongoing

effectiveness of the MOC system, and bases for changes and designs. Had Didion included such items in its MOC program, design issues such as insufficient transport velocity or connecting equipment without sufficient safeguards might have been detected through the MOC program, the incident might have been prevented or mitigated.

8. The lack of OSHA prescriptive requirements for Management of Change systems in grain handling facilities or other facilities with combustible dust hazards can result in process changes that create unrecognized hazards, leading to significant combustible dust incidents. Had Didion been required to maintain a robust MOC program, the temporary MOC downstream of the North and South BMs implemented the day of the incident, along with other changes that allowed combustible dust accumulation in dust collection systems, could have been more thoroughly reviewed and hazards mitigated, potentially mitigating the incident consequences.

Incident Investigation

1. After a 2012 South BM fire, Didion did not recognize the significant hazard that smoldering material reaching a downstream dust collector posed, and consequently did not recommend or take corrective actions to prevent it.
2. Didion did not ensure that the resulting corrective actions were effective immediately after implementation or that they were effective over time, allowing this scenario to occur again during the May 31, 2017, incident.
3. Didion's incident investigation into a 2013 flash fire did not identify any gaps regarding controlling ignition sources or personal protective equipment for mill operations employees. Didion's incident investigation made no connection to the inherent flash fire and explosive hazards of corn dust as a result of this incident, and therefore no relevant corrective actions were created, assigned, or completed, which could have prevented or mitigated the consequences of the May 31, 2017, incident.
4. Although Didion had a known, chronic issue with size reduction equipment discharge lines plugging and causing a fire, Didion did not effectively address this safety hazard. Previous incidents involving this hazard were not thoroughly investigated and did not result in effective corrective action that prevented recurrence, such as the likely starting point of the smoldering fire on the night of the May 31, 2017, incident.
5. Didion's investigation of prior incidents was severely inadequate. Didion experienced incidents that were similar to or nearly identical to the May 31, 2017, incident at least six times in the previous five years, but Didion never took appropriate action to prevent recurrence. Process fires became normalized at Didion, which contributed to the response during the night of the incident.
6. Didion did not incorporate available industry guidance into its Incident Management procedure that might have prevented or mitigated the consequences of the May 31, 2017, incident. Didion's Incident Management procedure lacked guidance and a system to track and resolve incident investigation findings and recommendations, a process to review findings and recommendations with affected personnel, effective root cause analysis, review of existing control measures and underlying systemic factors, and a system to ensure that corrective actions adequately prevented recurrence or monitored the effectiveness of actions taken. Had Didion incorporated available industry guidance for incident investigations, Didion could have further investigated prior events and implemented effective corrective actions that could have mitigated or prevented the May 31, 2017, incident.
7. The NFPA guidance for incident investigation management systems has gaps that allow some combustible dust incidents to continue to occur. These gaps include not requiring that causal factors and root causes be accurately identified and not ensuring that investigations identify and recommend

preventive measures that reduce the probability of recurrence and/or mitigate as appropriate for the potential consequences. Had Didion incorporated CCPS guidance for incident investigations, Didion could have more accurately identified causal factors in previous incidents, reduced probability of recurrence, and mitigated or prevented the May 31, 2017, incident.

8. Didion's incident investigation management system did not thoroughly analyze hazards, accurately determine what happened, accurately identify root causes and causal factors, properly identify preventive measures, ensure that follow-up actions were taken, or evaluate corrective action effectiveness, and therefore was ineffective. Didion missed critical opportunities to address significant combustible dust hazards in previous incidents and near misses in the mill facility before a catastrophic event occurred. Had Didion thoroughly investigated these previous incidents and near misses, the May 31, 2017, incident may have been prevented or mitigated.
9. The lack of OSHA prescriptive requirements for incident investigation management systems in grain handling facilities can result in unrecognized or improperly mitigated hazards, leading to significant combustible dust incidents. Had Didion been required to develop and implement an incident investigation program, Didion could have identified and corrected the repeated factors that contributed to the development of smoldering fires, flash fires, and explosions during the incident.

Process Safety Information

1. Had Didion electronically stored information, or stored it in a remote location, both Government and Didion investigators could have better evaluated the Process Safety Information involved in the incident, which is critical for conducting a high-quality incident investigation and identifying incident causes.
2. Didion did not maintain adequate Process Safety Information, which contributed to Didion's failure to identify, evaluate, and adequately address process hazards and implement adequate engineering controls and building design that could have prevented the incident or minimized its consequences.
3. The OSHA *Grain Handling Facilities Standard* does not address the process safety or design information required to perform effective DHAs, hazard assessments, or safe operating decisions, which could mitigate combustible dust hazards such as those that resulted in the explosions and fires during the Didion incident.

Management of External Audits and Inspections

1. Didion did not have an adequate audit and inspection program to address the findings and recommendations that were generated from these actions. Furthermore, the deficiencies identified from the OSHA and insurance audits and inspections, if implemented in a timely fashion, could have mitigated the combustible dust fires and explosions that occurred during the 2017 incident.
2. Years before the incident, OSHA identified inadequate deflagration engineering controls at Didion, but Didion did not address the hazards. Had Didion addressed the identified hazards, the incident could have been prevented or mitigated.
3. Didion's insurance company identified several gaps related to combustible dust during the 2012 audit and provided recommendations to mitigate the hazards of these items. At the time of the incident, the lack of suppression and adequate venting increased the severity of the incident. Had Didion assessed the deflagration controls and electrical classifications, as identified by the insurance company, Didion could have implemented controls that could have mitigated the severity of the incident.
4. The Didion responses provided for the insurance audit did not address the existing hazards within the mill facility. There was no evidence that any samples were taken of the material to determine if it was

combustible dust. The response for engineering controls only indicated the application in future installations; however, there was no indication that any existing hazards would be addressed. Had Didion reviewed the existing systems for hazards and tested the materials for combustibility, Didion could have recognized the deficiencies in the safety systems that managed the combustible dust in the processes and implemented controls that could have mitigated the severity of the incident.

5. Didion did not appropriately address the OSHA inspection recommendations from 2013 to assess combustible dust and mitigate the identified hazards. Additionally, Didion did not have an audit program that assigned responsibility to employees for follow-up on the action items. Had Didion incorporated engineering controls using engineering standards and guides, such as NFPA 61, NFPA 68, and NFPA 69, the incident could have been prevented or mitigated.
6. The lack of involvement and transfer of knowledge from upper management to the milling employees hindered the awareness of the combustible dust hazards present within the mill. The CSB concludes that the Didion audit process did not account for the turnover of personnel that should have triggered the re-assignment of actions to ensure the completion of critical recommendations that could have prevented or mitigated the incident. Had Didion ensured the transfer of knowledge and re-assignment of action items, Didion management could have been aware of prior inspections, which identified deficiencies in the management of combustible dust, and implemented recommendations that could have prevented or mitigated the incident.
7. OSHA's *Grain Handling Facilities Standard* does not adequately require facilities to either undergo safety audits or address safety recommendations as part of the regulatory requirements. Had Didion been required to undergo safety audits and address recommendations, Didion could have been required to address deficiencies in its facility related to combustible dust, which could have prevented or mitigated the severity of the incident.

<u>Emergency Preparedness</u>

1. Didion did not provide specific instructions to employees for abnormal conditions in its emergency response plan, such as the smoldering material and unidentified smoke sources. Furthermore, the emergency response plan did not identify when to notify employees to evacuate the facility or how to notify all employees. The lack of a defined response for upset conditions likely contributed to the severity of the incident.
2. Didion's practices during the incident did not match the policy or training for emergency response, such as evacuating the mill facility when smoke was observed. Had Didion contacted emergency responders, shut down the mill facility, and evacuated the mill when the smoke was first observed, the severity of the incident could have been greatly reduced.
3. Didion incorrectly treated fires in process equipment as incipient fires that could be treated with fire extinguishers, which caused the employees to attempt to locate the source of smoke rather than evacuate the facility prior to the escalation from the smoldering fire to explosions. Didion's incipient fire training program did not adequately inform employees of the potential hazards of the transition of incipient combustible dust fires to flash fires or explosions. Had Didion's training instructed employees to not fight unidentified fire inside process equipment, the employees could have shut down and evacuated the facility and prevented the injuries and fatalities that occurred due to the fires and explosions that occurred the incident.
4. The Didion emergency response plan did not incorporate guidance from the NFPA to provide procedural instructions on responding to upset conditions or when to trigger evacuations, such as when a fire cannot be promptly controlled. Had Didion provided followed guidance on emergency response practices, such as those in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in*

Agricultural and Food Process Facilities, the employees could have responded to the developing emergency and evacuated, which could have mitigated the severity of the incident.

5. Didion did not have a communication method to immediately notify all employees of upset conditions or emergency situations to trigger an evacuation, which likely contributed to the injuries and fatal injuries of non-essential employees who were not actively involved in troubleshooting. The reliance on radio communications delayed the potential employee evacuation prior to the incident.
6. Didion's training program was inadequate to ensure the employees performed the tasks as directed by the training documentation. Rather, the mill facility's standard practice placed employees in potentially hazardous scenarios while trying to investigate potential sources of smoke or fire. Furthermore, the practice of employees identifying smoldering fires and fighting incipient fires, rather than evacuating, was a widespread practice that placed employees in potentially hazardous situations.

Personal Protective Equipment

1. Didion did not require its employees to use flame-resistant garments for protection against potential thermal injuries from combustible dust flash fire events that contributed to the severity of the injuries in the incident.
2. Didion did not assess the milling processes for the hazard of flash fires and dust explosions either prior to the incidents that resulted in employee injuries, or after those incidents. Had Didion assessed and implemented personal protective equipment for potential flash fire hazards, the severity of the injuries could have been mitigated.
3. The lack of prescriptive requirements for the use or assessment for flame-resistant personal protective equipment (PPE) in grain handling facilities that present combustible dust hazards can result in underspecifying the PPE necessary to keep employees safe. Had the *Grain Handling Facilities Standard* required the use of flame-resistant PPE, Didion could have been required to implement employee protections that could have prevented or mitigated the numerous burn injuries, including the injuries that resulted in hospitalizations.
4. Didion did not appropriately address the hazard of flash fires and dust explosions in prior incidents that resulted in multiple employee injuries, including several hospitalizations due to the severity of the burns.

Process Safety Leadership

1. Didion did not maintain a sense of vulnerability in its operations resulting in the inaccurate belief that dust explosions could not occur at its facility which allowed hazards to be underestimated, resulting in the incident and the lack of protections for the employees.
2. While some of Didion's leadership may have recognized the hazards of combustible dust within the facility, the failure to communicate the hazards, act upon the hazards, and mitigate risk resulted in the inadequate engineering and administrative controls to prevent the dust explosion.
3. Didion did not utilize or defer to expertise prior to the incident regarding the hazards of combustible dust within the process. Didion utilized cost as the basis for the installation of engineering controls rather than the potential consequences of hazards and the expertise of others more familiar with combustible dust.
4. Didion normalized deviance regarding smoldering fires, which caused employees to not recognize the significance of fire inside the process equipment and the potential for it to transition to catastrophic dust explosions.
5. Prior to the incident, Didion had a poor safety culture and weak safety programs due to inadequate process safety leadership. The lack of a sense of vulnerability, the lack of understanding and acting upon hazards, the failure to defer to expertise, and the normalization of deviance resulted in the inadequate

response to industry-recognized combustible dust hazards, allowing the injuries and fatalities to occur when the dust explosions occurred, and the buildings collapsed.

Regulatory Coverage of Combustible Dust

1. The OSHA *Grain Handling Facilities Standard* did not confer adequate regulatory requirements to assess and abate potential combustible dust hazards, such as those present at Didion before the incident. Had Didion been required to implement the engineering controls, such as deflagration isolation, the incident severity could have been mitigated.
2. There is no mechanism or framework for follow-up inspections when issuing a Hazard Alert Letter (HAL). Had Didion been required to implement additional engineering controls, such as those identified in the HAL, Didion might have improved its deflagration isolation controls, which could have limited the spread of the fires and explosions and reduced the severity of the incident.
3. The insufficient regulatory oversight of processes and facilities that handle combustible dust contributed to the incident at Didion. The CSB also concludes that the OSHA Combustible Dust National Emphasis Program does not adequately assess for factors that can result in combustible dust fires and explosions that result in serious injuries and fatalities, such as deflagration isolation controls.

5.2 Cause

The CSB determined the cause of the dust explosions and collapsed buildings was the ignition of combustible corn dust inside process equipment which transitioned to multiple explosions. Contributing to the severity of the explosions was Didion's lack of engineering controls, which allowed the fire and explosions to propagate through the facility uncontrolled. The uncontrolled propagation of fire and explosions subsequently caused secondary explosions due to the inadequate fugitive dust management.

Due to the number of weaknesses in the implementation and management of safety programs, Didion exhibited a lack of safety leadership and a poor safety culture. Didion's inadequate safety management systems for combustible dust failed to mitigate the potential hazards of combustible dust in the process. Didion inadequately managed changes to process equipment, failed to maintain critical safety information, and failed to incorporate lessons learned from prior incidents.

Didion's inadequate emergency preparedness, which failed to inform or train its employees to safely respond to a smoldering fire, contributed to the fatalities and serious injuries. Also contributing to at least one fatality and three serious injuries was Didion's lack of flame-resistant personal protective equipment that could have protected employees from exposure to the flash fires.

Contributing to all five fatalities and all 14 serious injuries was Didion management's failure to abate combustible dust hazards identified during external inspections, which resulted in Didion continuing to operate despite knowledge of these hazards.

6 Recommendations

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 Previously Issued Recommendations Superseded in This Report

2006-1-H-1 (From the 2006 Combustible Dust Hazard Investigation), 2008-05-I-GA-R11 (From the 2008 Imperial Sugar Investigation), and 2011-04-I-TN-R2 (From the 2011 Hoeganaes Corporation Flash Fires Investigation

Issue a standard designed to prevent combustible dust fires and explosions in general industry. Base the standard on current National Fire Protection Association (NFPA) dust explosion standards (including NFPA 654 and NFPA 484), and include at least - hazard assessment, - engineering controls, - housekeeping, - building design, - explosion protection, - operating procedures, and - worker training.

Superseded by **2017-07-I-WI-R10** *to OSHA in Section 6.2.2*

2011-4-I-TN-1 (From the 2011 Hoeganaes Corporation Flash Fires Investigation)

Ensure that the forthcoming OSHA Combustible Dust Standard includes coverage for combustible metal dusts including iron and steel powders.

Superseded by **2017-07-I-WI-R10** *to OSHA in Section 6.2.2*

6.2 New Recommendations

6.2.1 Didion Milling

2017-07-I-WI-R1

Contract a competent third party to develop a comprehensive combustible dust process safety management system, such as OSHA's *Process Safety Management* standard or the requirements in the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust,* Chapter 8, which includes, at a minimum, the following elements:

j. Management of Change for combustible dust;
k. Process Safety Information management;
l. Management of Audits and Inspections;
m. Fugitive Dust Management;
n. Incident Investigation;
o. Dust Hazard Analyses;
p. Management of Engineering Controls for combustible dust;
q. Personal Protective Equipment; and
r. Emergency Preparedness.

2017-07-I-WI-R2

Contract a competent third party to develop and implement modifications to the pneumatic conveying and dust collector ductwork systems in accordance with guidance such as NFPA 61, *Standard for the Prevention of Fires* *and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, and NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, to include, at a minimum:

a. Ensure minimum required transport velocity is maintained throughout the system.
b. Implement a periodic inspection and testing program for pneumatic conveying and dust collector ductwork systems, following industry guidance such as NFPA 91, *Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids,* and FM Global guidance. The program should include cleaning on a set frequency and measuring transport velocities on a routine basis to ensure proper system function.

2017-07-I-WI-R3

Contract a competent third party to perform dust hazard analyses (DHAs) on all buildings and units that process combustible dust. Ensure that the DHAs are revalidated at least every five years. Implement pre-deflagration detection, deflagration venting, deflagration suppression, deflagration isolation, and deflagration pressure containment engineering controls identified in the initial and revalidation DHA in accordance with NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, NFPA 69, *Standard on Explosion Prevention Systems*, and NFPA 652, *Standard on the Fundamentals of Combustible Dust*.

2017-07-I-WI-R4

Contract a competent third party to assess and implement engineering controls for the structural design and venting requirements of the reconstructed facility to ensure they meet the requirements and guidance in NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, for adequacy of venting capacity.

2017-07-I-WI-R5

Incorporate recording any paper-based process safety information into Didion's existing electronic records management system so that the information can be reliably retained, retrieved, and analyzed in the event of a catastrophic incident.

2017-07-I-WI-R6

Contract a competent third party to perform personal protective equipment hazard analyses, such as those prescribed by NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* and require appropriate flame-resistant garments for all operations that handle combustible dusts during normal and upset conditions.

2017-07-I-WI-R7

Contract a competent third party to update the facility emergency response plan and train all employees on updated emergency response plan. The update should include the guidance in NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, and NFPA 652, *Standard on the Fundamentals of Combustible Dust,* Chapter 8 and Section A.8.10.1, which includes, at a minimum, the following elements:

a. A signal or alarm system;
b. Emergency shutdown procedures;

c. Provide instructions for when and how to trigger emergency evacuations;
d. Provide instructions for when to notify emergency responders for need of assistance;
e. Response to potential fire scenarios, such as smoldering fires inside equipment; and
f. Prevent firefighting of process fires inside equipment.

2017-07-I-WI-R8

Contract a competent third party to assess and update the pre-deflagration detection and suppression engineering controls, such as those discussed in Chapter 9 of the 2019 edition of NFPA 69, *Standard on Explosion Prevention Systems*, for adequacy to detect and alarm employees of an emergency situation, such as a smoldering fire, and trigger an evacuation.

2017-07-I-WI-R9

Contract a competent third party to develop and implement a process safety leadership and culture program, based on the guidance of the CCPS's *Guidelines for Auditing Process Safety Management Systems* and *Process Safety: Leadership from the Boardroom to the Frontline*. The program should include, at a minimum, the following elements:

h. A process safety policy;
i. A process safety leadership and culture committee;
j. Appropriate goals for process safety;
k. A commitment to process safety culture;
l. Leading and lagging process safety metrics;
m. Process Safety Culture Assessments; and,
n. Engagement with external process safety leadership and culture experts.

6.2.2 Occupational Safety and Health Administration

2017-07-I-WI-R10

Promulgate a standard for all industries that handle combustible dust, which should be based on the requirements of current NFPA combustible dust standards, including NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, NFPA 484, *Standard for Combustible Metals*, NFPA 652, *Standard on the Fundamentals of Combustible Dust*, NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, NFPA 655, *Standard for Prevention of Sulfur Fires and Explosions*, NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities,* or a successor standard. At a minimum, the standard should include the following elements:

a. Hazard Recognition;
b. Dust Hazard Analysis;
c. Management of Change;
d. Incident Investigation;
e. Engineering Controls;
f. Building Design;
g. Fugitive Dust Management;
h. Operating Procedures;
i. Process Safety Information;

j. External Audit Management;
k. Training;
l. Emergency Response; and
m. Personal Protective Equipment.

2017-07-I-WI-R11

Following implementation of CSB Recommendation No. 2017-07-I-WI-R10, update the *Grain Handling Facilities Standard* to clarify grain handling facilities with combustible dust are covered by the new Combustible Dust Standard.

2017-07-I-WI-R12

Develop a program to trigger follow-up inspections when hazard alert letters are issued for combustible dust hazards and there is insufficient evidence to demonstrate that those hazards have been abated.

6.2.3 National Fire Protection Association

2017-07-I-WI-R13

Update NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*, or a successor standard, to incorporate, at a minimum, the following elements:

1. Unify the requirements for performing dust hazard analyses to remove equipment exemptions and require the assessment of all processes, such as cyclones, as required in:
    a. The 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*
    b. Chapters 3, 5, and 6 of the CCPS's *Guidelines for Combustible Dust Hazard Analysis*.
2. Incorporate the additional guidance for Management of Change to include but not limited to:
    a. Harmonize the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, requirements for section 8.12.2.4, modifications to operating and maintenance procedures, and section 8.12.2.4, employee training requirements.
    b. Chapter 3 and Appendix B of the CCPS's *Guidelines for the Management of Change for Process Safety,* such as addressing temporary changes, operating and maintenance procedures, employee training, and dust testing results, to standardize MOC requirements across all industries that handle combustible dust.
3. Update the requirements for incident investigation management systems, to include but not limited to:
    a. Incorporate the optional guidance of the 2019 edition of NFPA 652, *Standard on the Fundamentals of Combustible Dust*, as a mandatory requirement.
    b. Chapters 4 and 10 of CCPS's *Guidelines for Investigating Process Safety Incidents (3rd Edition)*.

7 KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Companies should ensure pneumatic transport and dust collection ductwork is designed to maintain a minimum transport velocity, and that companies should determine what the appropriate minimum velocity should be, based on their dust.
2. To ensure effective prevention and mitigation of combustible dust deflagrations, engineering controls (detection, suppression, isolation, venting, and pressure containment) must be utilized in conjunction with one another when designing a dust safety system.
3. Companies should review fire and building codes to determine the type of construction and evaluate any additional requirements based on the hazards of the materials being handled in the process.
4. Companies should ensure that the standards applied are applicable and appropriate to the hazards inside the facility. Food safety standards, for example, are appropriate for preventing food hazards such as pathogens and contaminants from reaching consumers but they are not intended to address workplace or process hazards such as combustible dust. Appropriate tools such as a DHA should be used to address process hazards like combustible dust.
5. Employers should utilize the findings of external audits to identify and correct hazards that could result in significant incidents resulting in injuries and property damage.
6. A fire inside an enclosed combustible dust handling process should not be considered an incipient fire because it cannot be characterized without the risk of increasing the severity of the incident.
7. To ensure that hazards are appropriately assessed, employers should consider abnormal and upset conditions when assessing personal protective equipment.
8. Safety regulations do not guarantee the safety of a process. Rather, regulations are the minimum threshold for maintaining safe operations. Largely unregulated hazards, such as combustible dust hazards, can exist in an otherwise regulated process. These hazards must be controlled beyond the existing regulatory requirements through the adoption of current industry standards and through the development of new regulations to prevent safety incidents.

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Appendix A—Simplified Causal Analysis (AcciMap)

Appendix B—Simplified Causal Analysis (Cause Map)

Appendix C—Combustible Dust Calculations

Appendix D—Atlas Structural Assessment

Appendix E—ABS Explosion Modeling

Appendix F—Technical Basis for CSB Dust Explosibility Testing Protocol

Appendix G – Dust Explosibility Testing Report

APPENDIX H—SUMMARY OF OSHA CITATIONS

Citation Number	Standard Cited	Summary of Citation
1	5(a)(1)	The employer did not furnish employment and a place of employment which were free from recognized hazards that caused or were likely to cause death or serious physical harm in that employees were exposed to grain product fire hazards associated with an indoor fluid bed dryer processing dry corn products which was not equipped with a means of fire protection.
2	1910.272(e)(1)	The employer did not provide training to employees at least annually and when changes in job assignment exposed them to new hazards on the general safety precautions and specific procedures and safety practices.
3	1910.272(l)(2)	Filter collectors installed after March 30, 1988 were not: (i) located outside of the facility; or (ii) located in an area inside the facility protected by an explosion suppression system; or (iii) located in an area inside the facility that is separated from other areas of the facility by construction having at least one hour fire-resistance rating, and which is adjacent to an exterior wall and vented to the outside.
4	1910.272(m)(1)(i)	Regularly scheduled inspections of at least the mechanical and safety control equipment associated with dryers, grain stream processing equipment, dust collection equipment including filter collectors, and bucket elevators were not accomplished.
5	1910.272(n)	The employer did not equip grain stream processing equipment (such as hammer mills, grinders, and pulverizers) with an effective means of removing ferrous material from the incoming grain stream.
6	5(a)(1)	The employer did not furnish employment and a place of employment which were free from recognized hazards that caused or were likely to cause death or serious physical harm in that employees were exposed to hazards associated with combustible grain dust explosion, deflagration or other fire hazards resulting from the failure to ensure that switch station flex hoses (part of a grain pneumatic conveying system) on the 5th floor of A mill were conductive, bonded and grounded.
7	1910.132(a)	Protective equipment, including personal protective equipment for the eyes, face, head and extremities, protective clothing, respiratory devices, and protective shields and barriers, were not provided, used, and maintained in a sanitary and reliable condition whenever it was necessary by reason of hazards of processes or environment, chemical hazards, radiological hazards, or mechanical irritants encountered in a manner capable of causing injury or impairment in the function of any part of the body through absorption, inhalation, or physical contact: The employer does not provide and ensure the use of flame-resistant clothing (FRC) to protect employees from burns due to potential flash fires.

Citation Number	Standard Cited	Summary of Citation
8	1910.272(d)	The employer did not develop and implement an emergency action plan meeting the requirements contained in 29 CFR 1910.38: The employer does not establish and maintain an approved employee alarm system compliant with the requirements of 1910.272(d), 1910.38(d), and 1910.165.
9 - 13	1910.272(j)(1)	The employer did not develop and implement a written housekeeping program that established the frequency and the method(s) determined best to reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces: The employer does not develop and implement a written housekeeping program that establishes the frequency and method(s) determined best to reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces.
14	1910.272(j)(3)	Compressed air was used to blow dust from ledges, walls, and other areas in grain handling facilities when machinery presenting an ignition source was not shut down, and when all other known potential ignition sources in the area were not removed or controlled: Compressed air is permitted to be used to blow dust from ledges, walls and other areas when all machinery in the area that presents an ignition source is not shut down and when other known potential ignition sources in the area are not removed or controlled.
15 - 17	1910.272(m)(1)(i)	Regularly scheduled inspections of at least the mechanical and safety control equipment associated with dryers, grain stream processing equipment, dust collection equipment including filter collectors, and bucket elevators were not accomplished: The employer does not perform regularly scheduled inspections of safety control equipment such as monitors, sensors, alarms, and associated interlocks on equipment such as size reduction equipment (hammer mills, gap mills, roller mills), fluid bed dryers, filter dust collectors, and bucket elevator legs.
18	1910.272(m)(1)(ii)	Lubrication and other appropriate maintenance in accordance with manufacturers' recommendations, or as determined necessary by prior operating records were not accomplished
19	1910.272(m)(2)	The employer did not promptly correct dust collection systems which were malfunctioning or which were operating below designed efficiency: The employer does not ensure that dust collection systems that are malfunctioning or operating below designed efficiency are promptly corrected.

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