DUST EXPLOSION RISK ASSESSMENT IN THE STORAGE BIN OF MICROCRYSTALLINE CELLULOSE BY FAULT TREE ANALYSIS

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ABSTRACT

A dust explosion in food ingredients production process can cause catastrophic loss of life, injuries, and destruction of buildings. This research aimed to assess dust explosion risk assessment in the storage bin of micro crystalline cellulose by fault tree analysis (FTA). To identify dust explosion possible cause by system failure such as machine, equipment, process control and administrative control failure. The FTA result showed 29 scenarios hazard identified which has impact on occupational health community, Environment, and property. The risk assessment process was identified 2 unacceptable risk that come from 2 scenarios possible root cause from the ignition source of the hot work performing without the isolation or the work performing not follow the hot work permit system. FTA with probability and reliability assigned of this event is 0.7657 and reliability is 0.2343. The study result of the dust explosion probability of failure on demand reduced from 0.0557 to 0.0236 and reliability increase from 0.9443 to 0.9764. The risk reduction credit come from the dust explosion hierarchy control measure implemented such as inherent safer process designed, engineering and administrative controls. This include isolation vales to prevent fire propagation to next process, fire suppression system to prevent fire propagation, bounding/grounding to prevent electrostatic discharge, explosion proof electrical area classification compliance, explosion venting to release deflagration pressure to safe location. Including employees training, housekeeping/dust removing.

Keywords: Fault Tree Analysis, Risk Assessment, Dust Explosion, Microcrystalline Cellulose

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INTRODUCTION

In many of dust explosion incident, workers and managers were failed to recognize the serious nature of dust explosion hazards. In the past, dust explosion cases have occurred in many places worldwide. In Thailand Department of Industrial Works (2013) reported of dust explosions incident is relatively low, there are only 5 incidents. The U.S. Chemical Safety and Hazard Investigation Board (CSB) identified 281 combustible dust incidents between 1980 and 2005 that led to the deaths of 119 workers, injured 718, and extensively damaged numerous industrial facilities. More recently, additional incidents have occurred. On February 7, 2008, a sugar dust explosion and subsequent fire at a sugar refinery in Port Wentworth, Georgia, caused 14 deaths and left many other workers seriously injured with severe burns. (CSB, 2009). The explosion was fueled by massive accumulations of combustible sugar dust throughout the packaging building. United States. Dust explosions had been an issue of concern among U.S. authorities since three fatal accidents in 2003, with efforts made to improve safety and reduce the risk of reoccurrence. The microcrystalline cellulose (MCC) is a term for refined wood pulp and is a valuable additive in pharmaceutical, food, cosmetic and other industries. The MCC product exclusivity test data are "A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape." (NFPA 654, 2017; NFPA 652, 2019). Required to address dust hazard analysis (DHA). Referring laboratory testing assess explosion characteristics of dust clouds (Stonehouse safety, 2018; BRE Group, 2017) all the MCC products are St 1 Class dusts, explosion severity measures Kst 68-192 bar/m, dP/dt: rate of pressure 250-709 bar/s, Pmax: 20 L Explosion severity 7.3-8.8 bar, minimum explosion concentration (MEC) typical 55-85 g/cu.m,, minimum ignition temperature (MIT) 400-555° C, minimum ignition energy (MIE) 200 to > 500 mJ, temperature Class T3. In addition to the familiar fire triangle of oxygen, heat, and fuel (the dust), dispersion of dust particles in sufficient quantity and concentration can cause rapid combustion known as a deflagration. If the event is confined by an enclosure such as a building, room, vessel, or process equipment, the resulting pressure rise may cause an explosion (OSHA 3371, 2009). Hassan et al. (2014) studies these five factors (oxygen, heat, fuel, dispersion, and confinement), are known as the "Dust Explosion Pentagon" (Abbasi & Abbasi, 2007). Therefore, based on the powder volume in the MCC storage bin MCC of dust explosion can be catastrophic and cause employee deaths, injuries, and destruction of entire buildings. The researcher is interested in the risk assessment methodology of dust explosions by applying Fault Tree Analysis (FTA) to identify factors that may contribute explosion from failure control of the dust explosion hierarchy control measure such as inherent safer process designed, the engineering control together with the administrative controls failure. Including the results obtained from the FTA analysis technique to calculate the probability of occurrence and the reliability of the safety integrity level (SIL) in the microcrystalline cellulose storage bin. The result of this study will be helpful as a guideline to set preventive measures and reduce problems before in accident occurred.

LITERATURE REVIEWS

Combustible dusts are finely divided combustible particulate solid, including combustible fibers/flying, That presents a flash-fire hazard or explosion hazard when suspended in air or the process-specific oxidizing medium over a range of concentrations (NFPA 652, 2019). In Thailand Department of Industrial Works (2013) has collected information about explosive dust were defined as material 420 µm or smaller (those passing through a U.S. No. 40 standard sieve) is now considered an appropriate size criterion. Particle surface area-to-volume ratio is a key factor in determining the rate of combustion. (NFPA 654, 2017). The "Dust Explosion Pentagon" In addition to the familiar fire triangle of oxygen, heat, and fuel (the dust), dispersion of dust particles in sufficient quantity and concentration can cause rapid combustion known as a deflagration It consists of five factors: dispersion of fine particles in the mixture, combustible powder, oxygen, confinement of the mixture and source of ignition (OSHA, 2013).

Figure 1 Dust Explosion Pentagon and Fire Triangle
Note: Refer to Department of Industrial Works (2010); OSHA 3644-04 (2013)

Domino effect of Dust Explosion: A primary explosion in processing equipment or in an area where fugitive dust has accumulated may dislodge more accumulated dust into the air or damage a containment system (such as a duct, vessel, or collector). As a result, if ignited, the additional dust dispersed into the air may cause one or more secondary explosions. These can be far more destructive than a primary explosion due to the increased quantity and concentration of dispersed combustible dust. Many deaths in past incidents, as well as other damage, have been caused by secondary explosions as show in the figure 2.

Figure 2 Domino effect of Dust Explosion
Note: Refer to Safety Practices guide for dust Explosion. Department of Industrial Works (2013)

Very important to known dust characteristics in your process material handling. To assess the potential for an explosion and to select the most appropriate basis of safety for any operation, the explosion characteristics of the dust(s), handled in the processes, should be determined (Hazardex, 2019). The explosion characteristics normally fall within one of two groups, “likelihood of an explosion (Ignition Sensitivity)” and “consequences of an explosion (Explosion Violence)”. Taken together these two groups define the dust explosion risk of a material. Eckhoff, R. K. (2003) Laboratory Testing to Determine “Ignition Sensitivity” Combustible dust testing generally refers to laboratory testing of finely divided combustible particulate solids that may presents a combustion/ flash-fire hazard or explosion hazard when suspended in air-or in another oxidizing medium. These tests are usually performed in specialist laboratories and include screening tests for combustibility and explicability, as well as tests that quantify dusts by determining ignition sensitivity and explosion severity characteristics. Minimum Ignition Energy (MIE), Minimum Ignition Temperature (MIT-cloud), Dust Layer (MIT-layer), Explosion Severity Test (Kst & Pmax). Minimum Exposable

Concentration (MEC) Limiting Oxygen Concentration (LOC) (Stonehouse safety, 2018; BRE Group, 2017).
Hazard Identification and Risk Assessment: Referring to Department of Industrial Works of Thailand. Ministerial Regulation on Hazard identification risk assessment and risk management, B.E; 2001, 2543. Hazard risk assessment can be performed through several techniques, including HAZOP, What-If Analysis, Event Tree Analysis, Checklist, Failure Mode and Effects Analysis, and Fault Tree Analysis (FTA). It is a graphic failure analysis tool used to deduct causes of undesired results and failures at the system level. It uses Boolean logic (i.e., AND gates and OR gates) to analyze the system and find the pathways that lead to the cause of failure. The analysis begins with the top event and identifies the causes and the logical relationships between the causes and the top event. The causes, called intermediate events, are examined simultaneously until the primary causes for every intermediate event have been identified. For drawing a fault tree diagram, can use logic gates and symbols along with specific Fault Tree Analysis shapes.
Risk Assessment: The determination of the risk associated with some event, task, or operation, followed by a decision regarding the acceptability or tolerability of that risk, may be qualitative, or quantitative and requires some type of "risk acceptance" criteria. The risk assessment procedures in accordance with Department of Industrial Works of Thailand. Ministerial Regulation on Hazard identification risk assessment and risk management, B.E; 2001, 2543. There are 3 steps: Step 1 to analyze the underlying causes that are representative of each situation. Step 2 estimate the likelihood of the occurrence and severity of the accident caused by the primary cause. Step 3 to calculate the risk level of each criterion situation and decide the risk level to lead to the determination. Preventive measure by deciding the level of risk is the multiplication of the level of likelihood with the severity of the impact on people, communities, environment, or property.
Brown, D. B. (1943) created Fault Tree Analysis with Probability and Reliability Assigned to shown top event probability calculation and reliability value as follows example in figure 3.

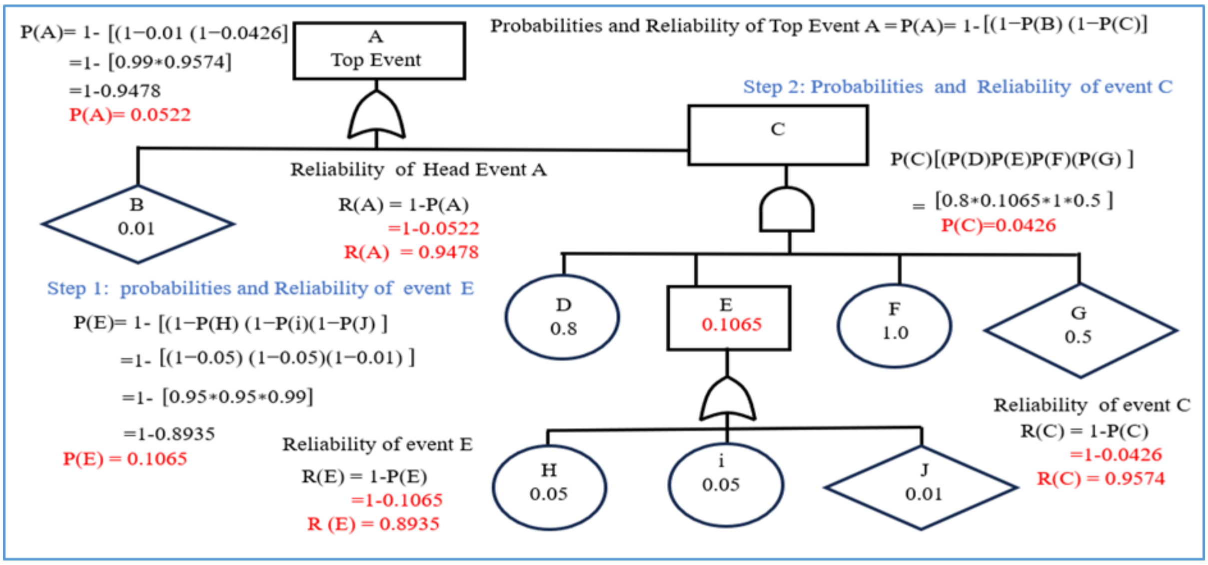

Figure 3 Example Fault Tree Analysis with probability assigned.
Note: Refer to Brown, D. B. (1943) Fault Tree Analysis. Systems analysis and design for safety -Safety systems engineering).

RESEARCH METHODOLOGY

This study referring methodology of hazard Identification and risk Assessment to Department of Industrial Works of Thailand. Ministerial Regulation on Hazard identification risk assessment and risk management, B.E; 2001, 2543. The dust explosion risk has been defined as Storage Bin of MCC that release combustible materials using FTA to assess explosion consequences and likelihood, respectively, and application of the hierarchy of controls such as inherent, engineering, and procedural safety (Abuswer et al., 2013). Logical analysis uses Boolean reductions that have been used to evaluate the effects of common events in fault trees where the occurrence of the top event does not depend on timing or sequencing of events (Taddao et al., 2022). Once a hazard has been identified, the likelihood and possible severity of injury or harm will need to be assessed before determining control measure. High risk will need to be addressed more urgently than low risk situations. Hazard identification and risk management is process as follows:

Step 1: Walkthrough survey and the field tour provides an excellent opportunity to identify human factors issues, drawing especially on the experience of the operators and mechanics in the area collected the machine, equipment, and process control system failure and collected data six years since 2017-2022. Area Classification survey follow NFPA 499 (2017) and ATEX zone classifications 20, 21, 22 (Powderprocess.net, 2022).

Step 2: Identified dust hazards: Assessment of the dangers and causes of dust explosion using the FTA technique. In table 1, according

Table 1 Symbols Used in FTA Analysis

Symbol	Name	Meaning
	And Gate: Many causes	If all conditions of input meet, this event occurs
	Or Gate : Any one cause	This event occurs when at least one of the event happens.
	Basic Event	A circle depicts an error or failure in an element or system component. A basic initiating failure fault.
	Fault Tree Event/ Intermedia Event/ Sub-Event	Sub-Event That result in a series of events until and accident is cause
	Undeveloped Event	Undeveloped events need no further breakdown. It is an event that is not further developed because the further analysis is not possible because of a lack of information. It is a basic event that does not need resolution.
	External Event (House Event)	A house symbol is generally accepted to occur. Generally, they have a fixed probability of 0 or 1.

Step 3: Fault Tree Analysis with Probability and Reliability Assigned

Step 4: Risk assessment: Evaluation Risk to assess the likelihood of occurrence and severity of accidents caused by the underlying cause. Calculate the risk level of each criteria situation and decide the level of risk to lead to the formulation of preventive measures. By deciding the level of risk is the multiplication of the level of likelihood with the severity of the impact on people, communities, environment, or Asset/property. Evaluation criteria in table 2, 3 and 4

Table 2 Likelihood Occurrence Rating

LIKELIHOOD OF OCCURRENCE		
Rating		Description
1	Unlikely	There is a rare chance of occurring such as never occurring in a period of 10 years or more. Probability greater than or equal to 0 but less than or equal to 0.01
2	Possible	There is a low probability of occurrence, for example, the frequency of occurrence occurs once in 5-10 years. Probability is greater than 0.01 but less than or equal to 0.1
3	Likely	There is a moderate probability of occurrence, for example, the frequency of occurrence occurs once in 1-5 years. Probability is greater than 0.1 but less than or equal to 0.2
4	Almost Certain	There is a high probability of occurrence, for example, the frequency of occurrence occurring more than 1 time in 1 year.Probability greater than 0.2 until equal to 1

Table 3 Consequence Severity Rating

Severity Rating		Consequences (Impact on people, community, environment ,asset/property)
1	Low	People: Minimal injury or first aid Communities: On-site -No impact on surrounding community or minor impact Environment: Minor environmental impact with can be controlled or return to normal quickly Asset/Property: Minor no property damaged. Any Property Damage ≤ $500 USD
2	Moderate	People: Medical treatment or restricted duty Community: Off-site -affecting communities around the plant and can be response in a short time Environment: Moderate environmental impact can be solved in a short time, incident to outside air with can be controlled or return to normal short time Asset/Property: Moderate property damage and can continue further production. Any Property Damage ≤ $2,500 USD but less than $ 500 USD
3	High	People: There is a serious injury or illness or lost time injury, or reversible health effects Communities: Off-site affecting the community around the factory. And it takes time to fix Environmental: Serious impact on the environment, it takes time to fix Asset/Property: the property is very damaged. and shutdown production in some parts. Any Property Damage ≥ $2,500 USD but less than $100,000 USD
4	Very High	People: Fatalities, permanent disabilities Communities: On-site -No impact on surrounding community or minor impact Environmental: has a very serious impact on the environment, requires resources and takes a long time to fix Asset/Property: Very damaged property and had to shut down all production. Property Damage ≥ $100,000 USD

Table 4 Decision Risk Level

Risk Rating	Results (Likelihood × Severity)	Risk Level	Response required for risks identified
1	1-2	Low	Negligible, no action required
2	3-6	Medium	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
3	8-9	High	High risk Actions must be taken to mitigate risks.
4	12-16	Very High	Unacceptable risk: the operation must be stopped, and corrective action required reduce the risk immediately.

Note: Table 1, 2, 3, 4 Refer to Department of Industrial Works of Thailand. Ministerial Regulation on Hazard identification risk assessment and risk management, B.E; 2001, 2543.

Step 5: Risk management plan: Identified control measure based on risk assessment and prioritization of accident situations. The most critical situation is defined as the situation with the very high-risk level of causing an accident, and must be take action to stop the job and take corrective preventive action first as follows response required in table 4
Step 6: Risk reduction credits compared before and after dust explosion hierarchy control implemented. Control measures must be periodical reviewed. Monitor for trends and patterns which may indicate increasing risk.

RESEARCH RESULTS

Step 1: Site surveys to inspection hierarchy control to gather information for information with the finding record and compared data of system failure six years (2017-2022)

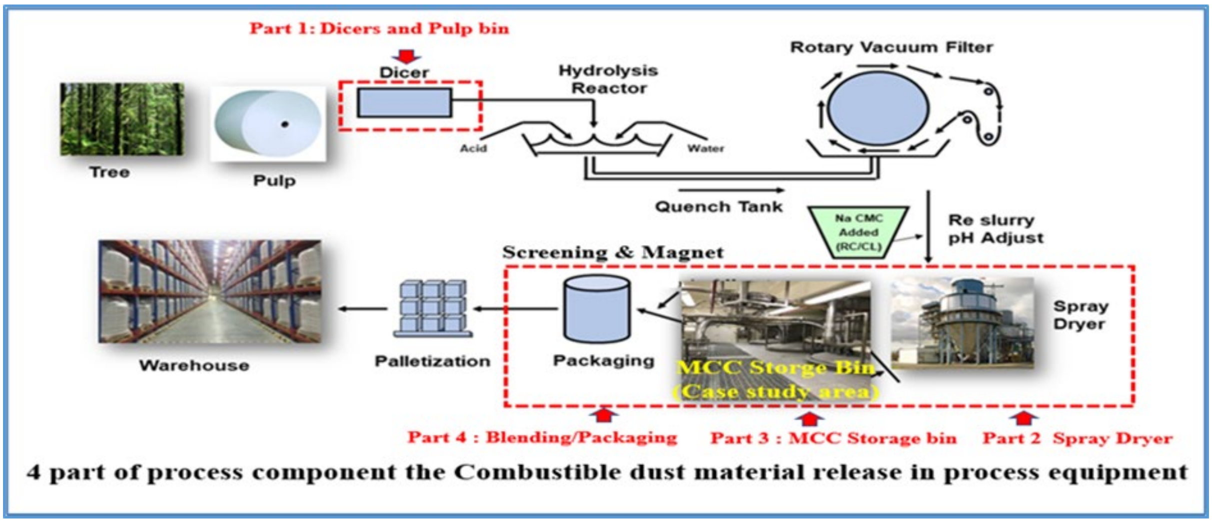

Figure 4 facility survey to identified case study dust explosion process.

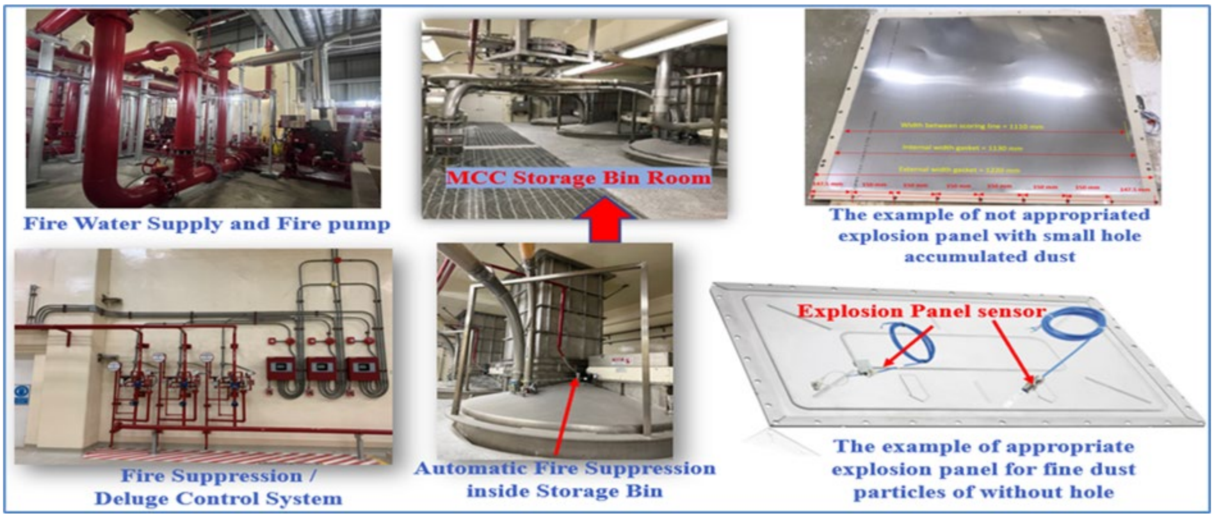

Figure 5 Fire and dust explosion prevention refer NFPA 68. (2018); NFPA 654. (2017).

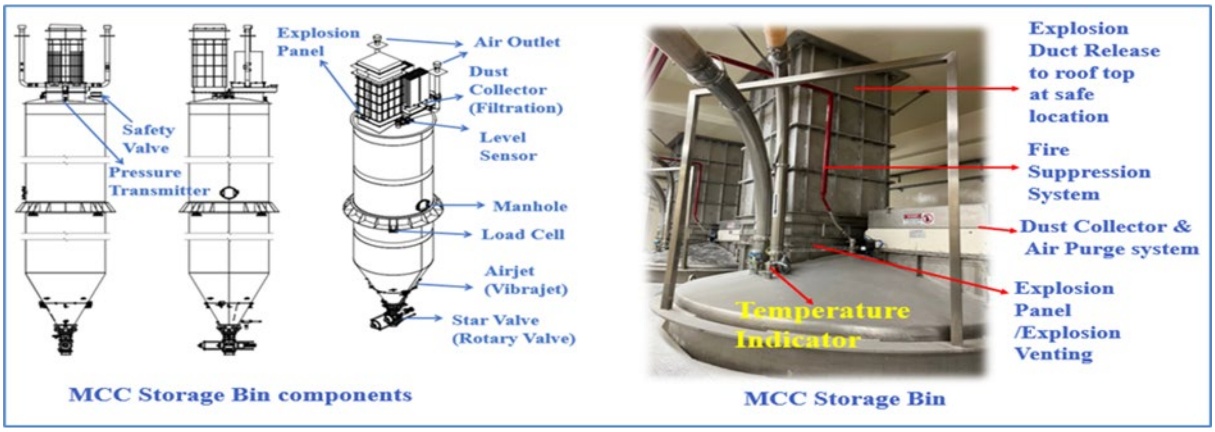

Figure 6 Site survey Storage bin safety device and process control

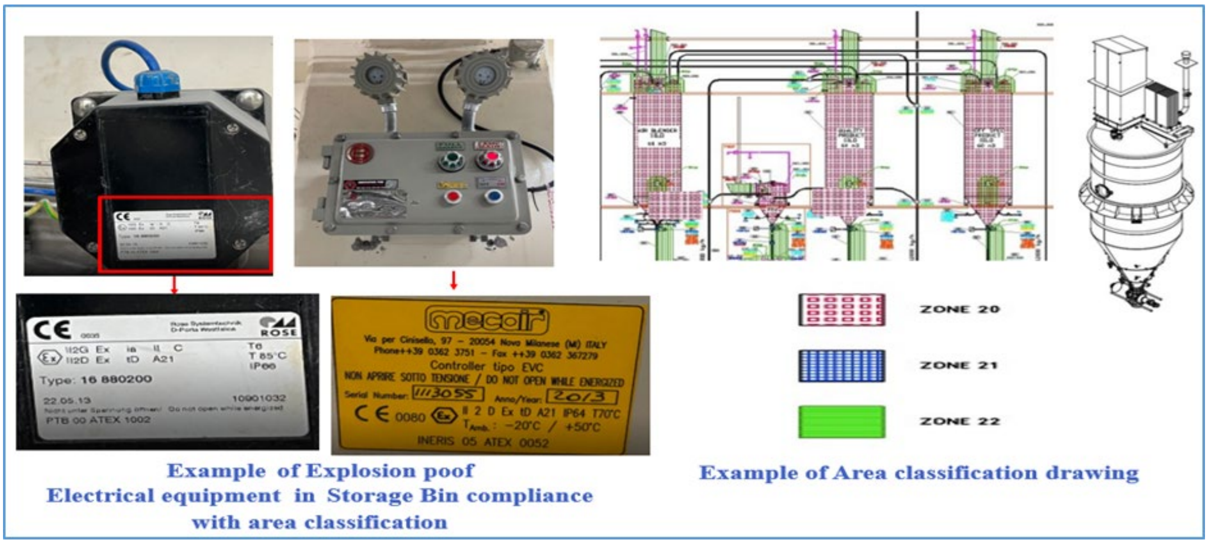

Figure 7 Explosion proof electrical equipment and Instrument Installations follow ATEX zone

Figure 8 Site survey Bounding /Grounding Installations.

Table 5 Example Site Survey Compared Data of System Failure Six Years (2017-2022)

Item	System/ Equipment	Functions	Collected data since 2017-2022		
Transfer Blower Positive Pressure Pneumatic Conveying from dryer and process equipment in storage bin			No. of Workplace Inspection	No. of Failure/ Abnormal	No. Normal
1	Rotary Valve / Isolation Valve	Normally open when the conveying of MCC products from Spray Dyer to the Storage Bin. In case interlocked shut down, there will be close with a gap of not more than 0.2 mm. there are Isolation Valve to prevent the fire propagation or blocked hot spark to the MCC storage bin or next process	15	2	13
2	Transfer Blower Storage Bin	Transfer Blower Positive Pressure Pneumatic Conveying that delivers product from Spray dryer to storage bin. In case interlocked shut down with flow rate, pressure, temperature and MCC level in the storage bin.	15	1	14
3	Explosion Relief Panel	An explosion relief panel is a one-time use of overpressure protection and has the function of protecting an installation against overpressure. These panels are used in a storage bin to acutely create an opening when a preset pressure occurs, so the pressure can be released activated set point at 100 mbar.	15	2	13

Step2: Identified dust Hazards: FTA is to effectively identify the cause(s) of system failure and mitigate the risks before it occurs the result shown in figure 9, 10, 11

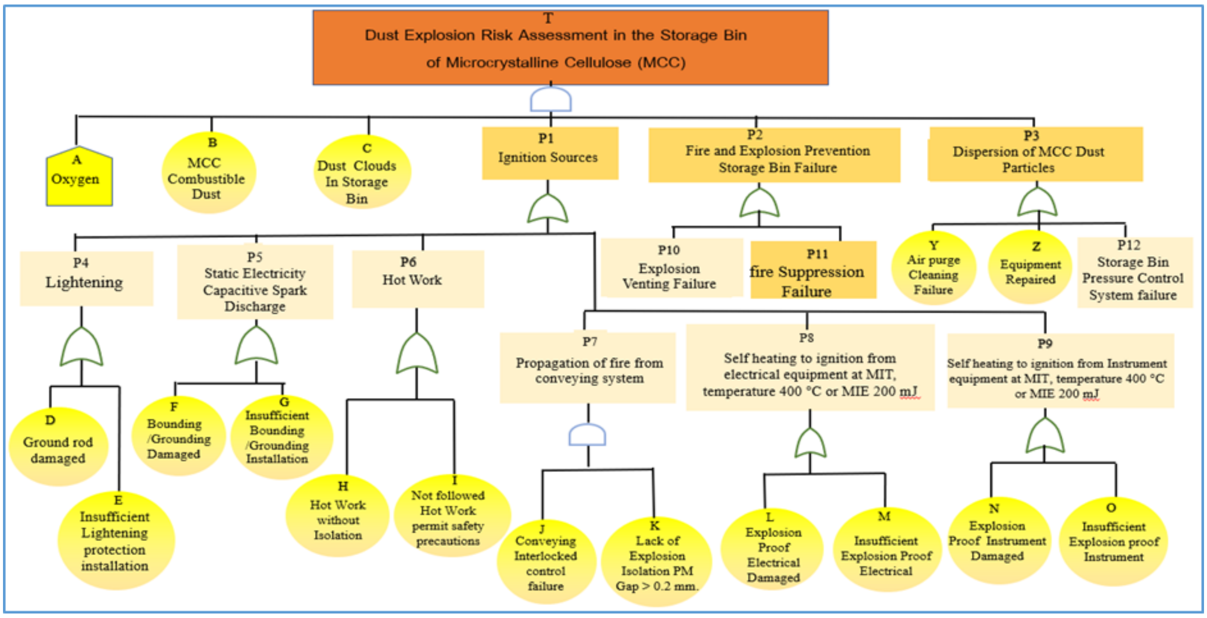

Figure 9 FTA diagram cause of ignition success failure (P1) and P2-P12.

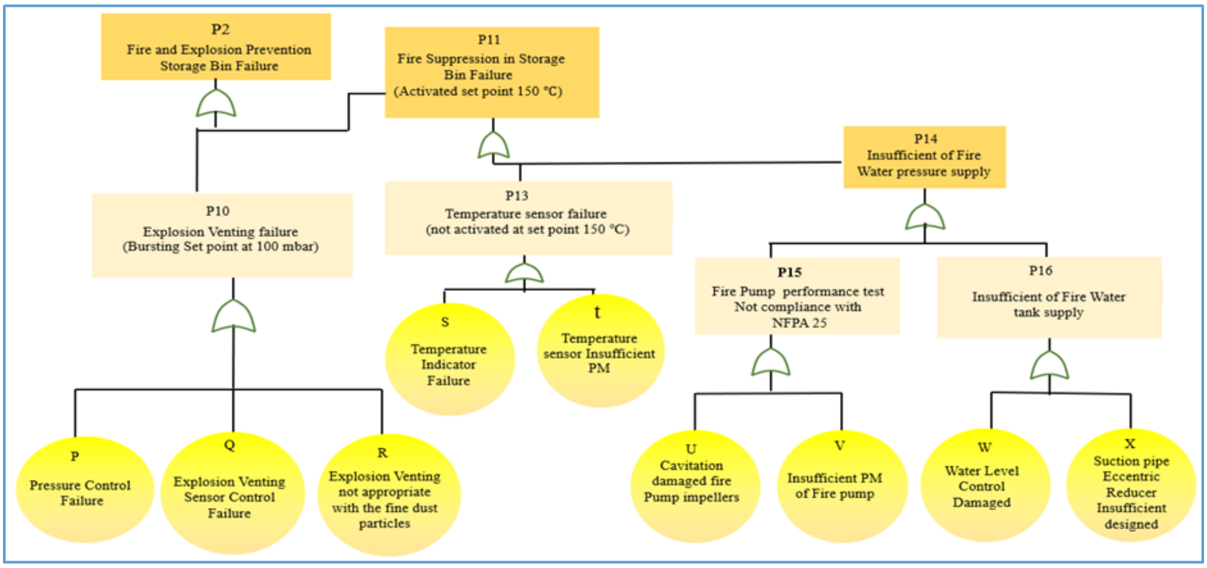

Figure 10 FTA diagram cause of fire and explosion protection failure (P2)

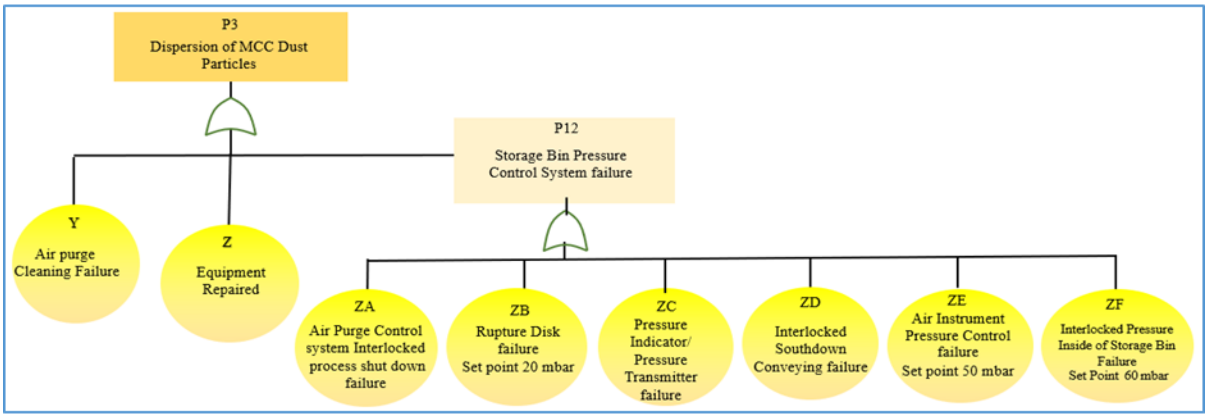

Figure 11 FTA diagram cause of Dispersion of MCC Dust Particles failure (P3)

Fault tree analysis consists of “events” and “logic gates,” which connect the events to identify the cause of the top undesired event, failure from the Boolean algebra principle, the result was identified 29 basic event of system failure. The Top event is represented by T, the intermedia event is represented by the letters P1-P16 within the rectangles and the Basic Event are within circles represented by represent by the letters A-ZF. Possible root cause of MCC explosion occurs from 5 causes combined by using instead of (And gate), which are element one the amount of oxygen in the air represented by the letter A, element two is MCC combustible dust represented by the letter B , element tree the confinement of dust cloud (in the Storage Bin) is represented by the letter C, element four Ignition Source is represented by the letter P1. element five Dispersion of Dust Particles (MCC) is represented by the letter P3 and the researcher has further analyzed the part of element six Fire Suppression and Explosion venting Failure is Fire Suppression and Explosion venting Failure, represented by the letter P2.

Step 3: Fault Tree Analysis with Probability and Reliability Assigned

Based on Boolean Relationships Basic, hazard analysis using FTA technique represents the opportunity and reliability of protective devices and incidents was identified 29 basic event of system failure, and then FTA with Probability and Reliability Assigned to determine of top event probability calculation and reliability value as in figure 12, 13, 14, 15, and table 6

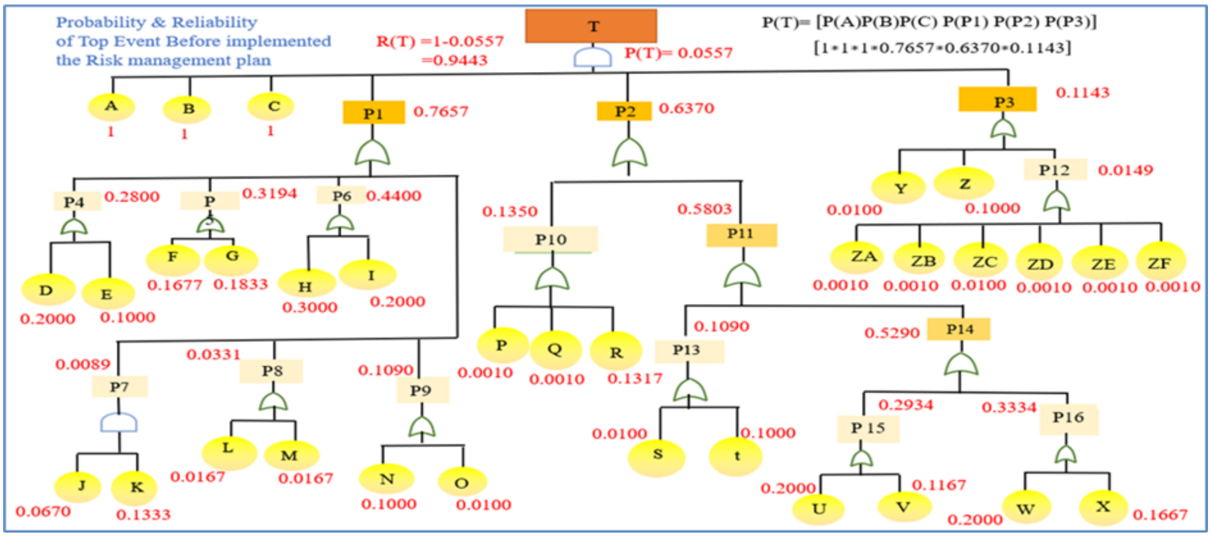

Figure 12 FTA with Probability and Reliability Assigned for (Top event) MCC Dust explosion.

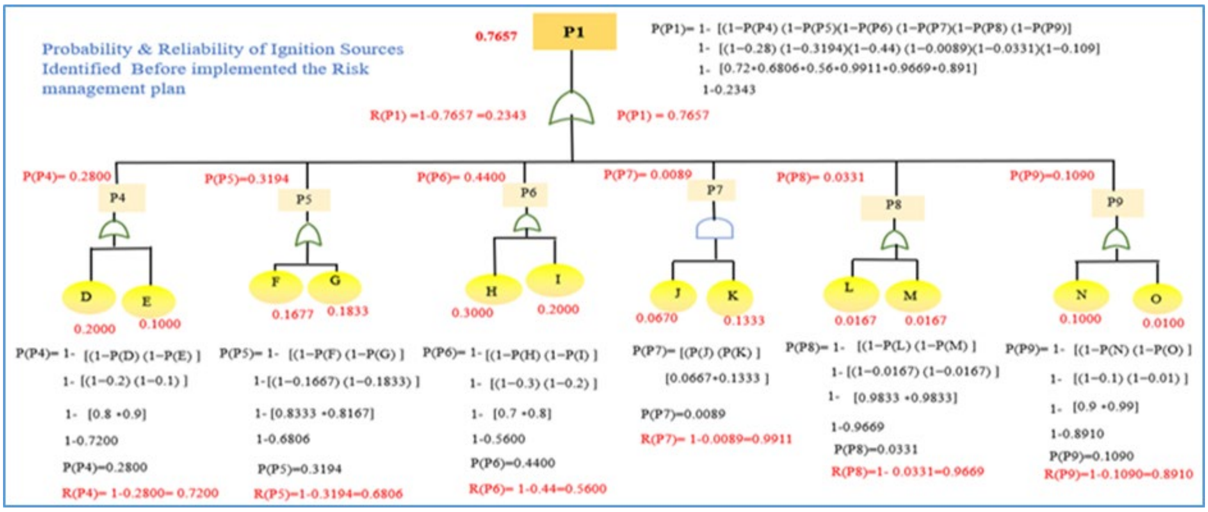

Figure 13 FTA with Probability and Reliability Assigned of Ignition Sources

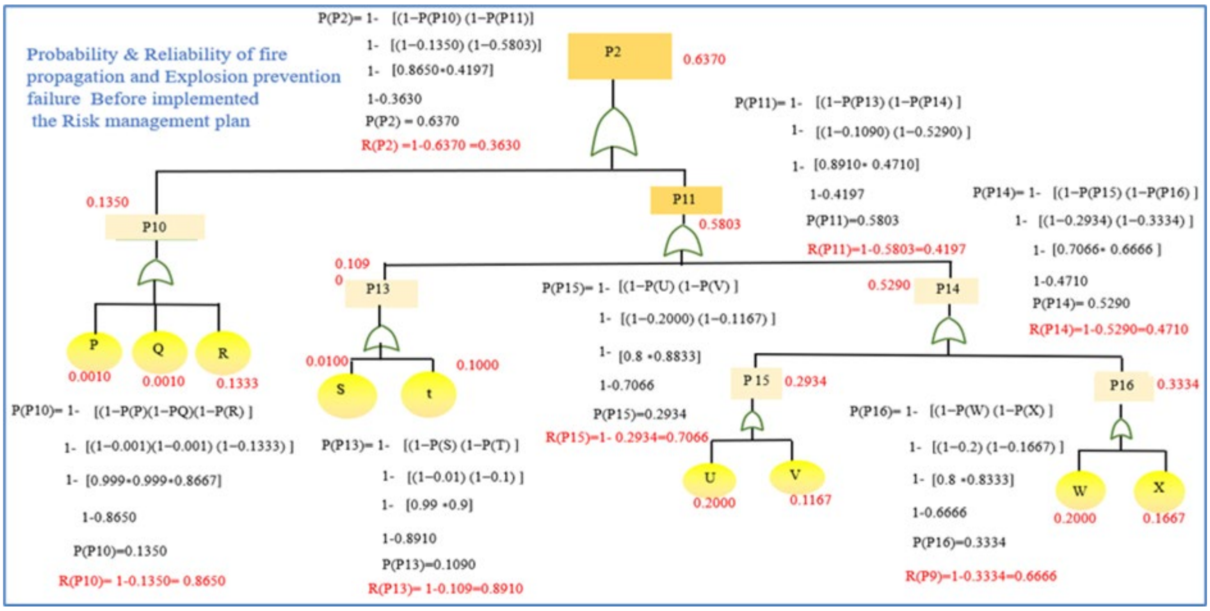

Figure 14 FTA with Probability and Reliability Assigned of fire & Explosion prevention.

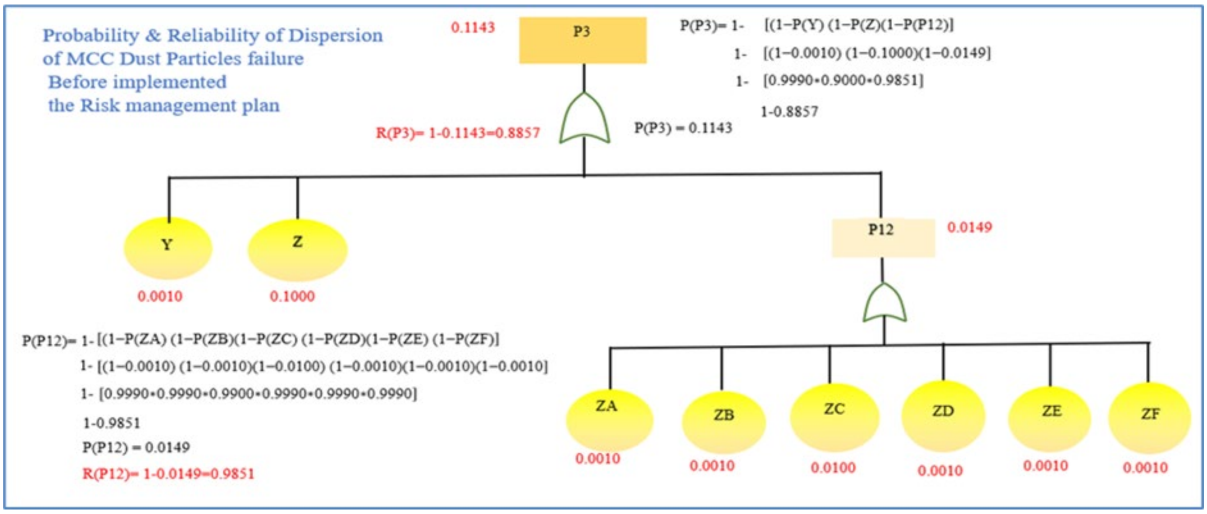

Figure 15 FTA with Probability and Reliability Assigned of Dispersion of MCC Dust Particles

Table 6 Boolean Relationships represents the opportunity and reliability Top event calculated.

Item	Dust Explosion Risk Assessment in the Storage Bin of Microcrystalline Cellulose by Fault Tree Analysis (Identify event scenarios 29 events.)	Number of Inspection (2017-2022)	Number of equipment Failue/abnormal/ Sinificant alarm sinal	Probbbility and Rilaiability Before improvement in six years (2017-2022)		Prioritization for Risk Assesement
				Probability of Failure on Demand (PFD)	Reliability =R(a)=1-P(a)	
T	Top Event= Dust Explosion in Storage Bin of Microcrystalline Cellulose T=Top event ,T=ABCP1P2 P3 T=ABC (D+E+F+G+H=I+(JK)+L+M+N+O) (P+Q+R+S+t+U+V+W+X) (Y+Z+ZA+ZB+ZC+ZD+ZE+ZF)	2193	0	0.0557	0.9443	probability typically expressed as a discrete value between 0 and 1, or as the corresponding percentage
P1	Ignition Sources= P1= P4+P5+P6+P7+P8+P9, P4=D+E ,P5= F+G,P6=H+I, P7=JK P8=L+M,P9=N+O P1=D+E+F+G+H=I+(JK)+L+M+N+O	430	34	0.7657	0.2343	Priority 1
P2	Fire and Explosion Prevention Storage Bin Failure P2= P10+P11, P10= P+Q+R, P11=P13+P14, P13=S+t, P15=U+V, P16=W+X P2= P+Q+R+S+t+U+V+W+X	245	32	0.6370	0.3630	Priority 2
P3	Dispersion of MCC Dust Particles = P3=Y+Z+P12, P12= ZA+ZB+ZC+ZD+ZE+ZF P3= Y+Z+ZA+ZB+ZC+ZD+ZE+ZF	300	0	0.1143	0.8857	Priority 3

Step4: Risk Assessment

According to table 2,3,4 and FTA result in table 6 as prioritization of scenario from opportunity and reliability calculated and the priority one, they are the ignition sources was identified work performing with hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits. Has a high likelihood of occurrence with a level of 4, and the impact on the people severity rating is very high (level 4) that affects a work performing in the hot working area, health effect will be disability or death. Affecting the community at level 1 because it is 238 meters away from neighbors. If there is an incident that does not affect the community around the factory or have a bit effect. Environmental impact level 2, moderate environmental impact, can be resolved in a short period of time. Impact the property at level 3, the property is very damaged and shutdown production in some parts, and had to shut down production in some parts. Therefore, the risk level of this scenario is 4 x 4 = 16 with decision risk level 4 that means unacceptable risk level. The example of risk assessment show in table 7.

Table 7 Example of Risk Assessment scenario P6 work performing hot work without Isolation.

Item	Scenarios	Consequence	Probability of Failure on Demand (PFD)	Reliability	Risk Assessment							Existing Measurement Control	Recommendation
						Severity							
					Likelihood	People	Community	Environment	Property	Results	Risk Level		
P6	work performing with hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits (P6=H+I)		0.4400	0.5600									
H	work performing with hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits	When work performing hot work (hot sparts) , such as welding, cutting, milling, grinding, without isolation/remove sources of dust deposits before Hot Work started, such as closing the valve Separating explosive dust from the hot work area. Spark heat (Hot Work) completes the fire components triangel and dust explotion patagon. the impact on the people severity rating is very high (level 4) that affects a work performing in the hot working area, health effect will be disability or death. Affecting the community at level 1 because it is 238 meters away from neighbours. If there is an incident that does not affect the community around the factory or have a bit effect. Environmental impact level 2, moderate environmental impact, can be resolved in a short period of time. Impact the property at level 3, the property is very damaged and shutdown production in some parts. and had to shut down production in some parts	0.3000	0.7000	4	4	1	2	3	#	4	1. There is a permit to work system in place such as hot work permit, energy isolation, Lock Out Tag Out Try Out, preventing the spread of explosive dust to the area where the Hot Work works. 2. workplace observation and inspection before permitting the start of welding, cutting, milling, and grinding. it must be ensured that hazards such as remove dust deposit sources, surface cleaning are controlled. Elimination of fuel sources in a radius of 11 meters. 3. Fire watch man, fire banket, Fire extinguishers are available and ready for use in the hot work area. 4. Certified fire watchers available with the hot work permit system training before permission hot work 5. Equipment inspection in good and safe condition with inspection tag ready to use. All cylinder vessel and regulators must be checked for availability.	1. Increasing the quality of inspection before granting work. both in the part of the job owner supervisor, production are owner and safety officers with the need to prepare the matter Comprehensive job safety analysis before starting work 2. Increase the frequency of inspections. Monitoring system for assessing compliance with the work permit system during work by the owner of the area and safety officers

As the result of risk assessment of 29 scenarios, it was found 2 scenarios that were unacceptable risk levels (very high risk as level 4). That the operation must be stopped, and corrective action required to reduce the risk level immediately with required appropriate risk management plan. The details of the event are as follows.

1) Hazards from working with Hot Work (hot sparks) such as welding, cutting, milling, grinding without isolation before started hot work. Able to ignite and explode away from the work area.

2) Hazards from performance hot work, such as welding, cutting, milling, and grinding work that are not followed safety precaution of the Hot Work permit system, do not remove the Sources of dust deposits.

For the high-risk level (level 3), there are 7 scenarios that require the address develop a risk reduction and mitigation plan

1) Caused by lightning strike due to the ground wire or the ground rod was damaged. Do not maintained the connection point of the conductor to the ground is rusted or damaged from construction excavation work.

2) Explosion Isolation system lack of maintenance. (With a blocking gap greater than 0.2mm).

3) Insufficient fire water supply due to malfunctioning water level control device
4) Insufficient fire water supply from suction pipe eccentric reducer insufficient designed
5) The Fire Pump performance test fails as required (the ratio between flow rate and pressure is less than 95%). due to impeller equipment damaged by impact or corrosion.
6) Insufficient PM not covered by the NFPA 25 standard required (NFPA 25, 2020).
7) Explosion Venting Pressure Relief Failure by improper selection of equipment, the equipment has small holes causing dust to accumulate inside of layer panel, causing to activating before the set point at 100 mbar. To damage the explosion panel and impact to shut down operation 8 hours for replace new set.
Step 5: Risk management plan: once determine the decision of risk, identified control measure based on risk assessment and prioritization of accident situations need to be address. Response required for risks identified need to follow table 4 and the prioritization result in the table 8 and the summarization of Risk level shown in table 9.

Table 8 Prioritization of 29 scenarios decision risk level

Item	Scenarios	Probability of Failure on Demand (PFD)	Reliability	Risk Assessment							Risk Management Plan Required (Response required for risks identified)
					Severity						
				Likelihood	People	Community	Environment	Property	Results	Risk Level	
P1	Ignition Source Indentified (P1= P4+P5+P6+P7+P8+P9)	0.7657	0.2343								
P6	Performing hot work (hot sparks) such as welding, cutting, milling, grinding (P6=H+I)	0.4400	0.5600								
H	Performing with hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits	0.3000	0.7000	4	4	1	2	3	16	4	Unacceptable risk: the operation must be stopped, and corrective action required reduce the risk immediately.
I	Performing hot work (hot sparks) such as welding, cutting, milling, grinding not follow safety precaution of the hot work permit system	0.2000	0.8000	3	4	1	2	3	12	4	Unacceptable risk: the operation must be stopped, and corrective action required reduce the risk immediately.
P4	Lightning strikes (P4=D+E)	0.2800	0.7200								
D	lightning strike due to the ground wire or the ground rod was damaged by Insufficient PM. Do not maintained the connection point of the conductor to the ground is rusted or damaged from construction excavation work.	0.2000	0.8000	3	3	1	2	3	9	3	High risk Actions must be taken to mitigate risks.
P7	Propagation of fire from the Transfer Blower (Positive Pressure Pneumatic Conveying conveying system) that carried the MCC product from the Spray dryer to the Storage Bin (P7=JK)	0.0089	0.9911								
K	Explosion Isolation system lack of maintenance. (with a blocking gap greater than 0.2mm).	0.1333	0.8667	3	2	1	2	3	9	3	High risk Actions must be taken to mitigate risks.

Table 8 (Continued)

Item	Scenarios	Probability of Failure on Demand (PFD)	Reliability	Risk Assessment								Risk Management Plan Required (Response required for risks identified)
				Likelihood	Severity				Results	Risk Level		
					People	Community	Environment	Property				
P2	Fire and Explosion Prevention Storage Bin Failure (P2=P10+P11)	0.6370	0.3630									
P11	The fire suppression system in the storage bin does not work as scheduled. (P11=P13+P14)	0.5803	0.4197									
P14	Insufficient fire water pressure (P14=P15+P16)	0.5290	0.4710									
P16	Insufficient fire water supply from the storage system (P16=W+X)	0.3334	0.6666									
W	Insufficient fire water supply due to malfunctioning water level control device	0.2000	0.8000	3	2	1	2	3	9	3		High risk Actions must be taken to mitigate risks.
X	Insufficient fire water supply from suction pipe eccentric reducer insufficient designed	0.1667	0.8333	3	2	1	2	3	9	3		High risk Actions must be taken to mitigate risks.
P15	Fire Pump performance test fails as required (P15=U+V)	0.2934	0.7066									
U	The Fire Pump performance test fails as required (the ratio between flow rate and pressure is less than 95%.) due to impeller equipment damaged by impact or corrosion	0.2000	0.8000	3	2	1	2	3	9	3		High risk Actions must be taken to mitigate risks.
V	Insufficient PM not covered by the NFPA25 standard required.	0.1167	0.8833	3	2	1	2	3	9	3		High risk Actions must be taken to mitigate risks.
P10	Explosion Venting not activated according to Set Point at 100 mbar (P10= P+Q+R)	0.1317	0.8683									
R	Explosion Venting Pressure Relief Failure by improper selection of equipment, the equipment has small holes causing dust to accumulate inside of layer panel, causing to activating before the set point at 100 mbar. To damage the explosion panel and impact to shut down operation 8 hours for replace new set.	0.1333	0.8667	3	2	1	2	3	9	3		High risk Actions must be taken to mitigate risks.
P5	Static Electricity Capacitive Spark Discharge (P5= F+G)	0.3194	0.6806									
G	Insufficient Bounding /Grounding Installation	0.1833	0.8167	3	2	1	2	2	6	2		Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
F	Bounding /Grounding Damaged	0.1667	0.8333	3	2	1	2	2	6	2		Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P4	Lightning strikes (P4=D+E)	0.2800	0.7200									
E	Insufficient Lightening protection installation	0.1000	0.9000	2	3	1	2	3	6	2		Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.

Table 8 (Continued)

Item	Scenarios	Probability of Failure on Demand (PFD)	Reliability	Risk Assessment							Risk Management Plan Required (Response required for risks identified)
					Severity						
				Likelihood	People	Community	Environment	Property	Results	Risk Level	
P9	Self-heating to ignition at MIT, temperature 400 °C or MIE 200 mJ from Instrument equipment that not qualified explosion proof (P9=N+O)	0.1090	0.8910								
N	Instrument equipment not qualified as Explosion proof due to equipment damaged (site survey not found) use Probability of Failure on Demand (PFD) of Safety Guard online of Defense	0.1000	0.9000	2	2	1	2	3	6	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P7	Propagation of fire from the Transfer Blower (Positive Pressure Pneumatic Conveying conveying system) that carried the MCC product from the Spray dryer to the Storage Bin (P7=JK)	0.0089	0.9911								
J	Interlocked conveying systems failure to stop conveying at the pressure control set point 60 mbar	0.0667	0.9333	2	2	1	2	3	6	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P8	Self heating to ignition from electrical equipment at MIT, temperature 400 °C or MIE 200 mJ (P8=L+M)	0.0331	0.9669								
L	Explosion-proof electrical equipment was defected	0.0167	0.9833	2	2	1	2	3	6	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
M	Insufficient Explosion Proof Electrical	0.0167	0.9833	2	2	1	2	3	6	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P9	Self-heating to ignition at MIT, temperature 400 °C or MIE 200 mJ from Instrument equipment that not qualified explosion proof (P9=N+O)	0.1090	0.8910								
O	Insufficient Explosion proof Instrument	0.0100	0.9900	1	2	1	2	3	3	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P10	Explosion Venting Failure (P10= P+Q+R)	0.1350	0.8650								
P	Storage Bin Pressure Control Failure	0.0010	0.9990	1	4	1	2	4	4	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
Q	Explosion Venting Sensor Control Failure	0.0010	0.9990	1	4	1	2	4	4	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P13	Temperature sensor failure (not activated at set point 150 °C) (P13=S+t)	0.1090	0.8910								
t	Temperature sensor Insufficient PM (not activated at set point 150 °C)	0.1000	0.9000	2	2	1	2	3	6	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
S	Temperature Indicator Failure	0.0100	0.9900	1	2	1	2	3	3	2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.

Table 8 (Continued)

Item	Scenarios	Probability of Failure on Demand (PFD)	Reliability	Risk Assessment								Risk Management Plan Required (Response required for risks identified)
				Likelihood	Severity				Results	Risk Level		
					People	Community	Environment	Property				
P3	Dispersion of MCC Dust Particles (P3=Y+Z+P12)	0.1143	0.8857									
Z	Equipment Repaired such as replacing the filter, replacing the measuring device inside storage bin	0.1000	0.9000	2	2	1	2	3	6	2		Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
Y	Air purge Cleaning Failure	0.0010	0.9990	1	2	1	2	3	2	2		Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.
P12	Storage Bin Pressure Control System failure (P12= ZA+ZB+ZC+ZD+ZE+ZF)	0.0149	0.9851									
ZC	Pressure Indicator/Pressure Transmitter failure	0.0100	0.9900	1	2	1	2	2	2	1		Negligible, no action required
ZA	Air Purge Control system Interlocked process shutdown failure	0.0010	0.9990	1	2	1	2	2	2	1		Negligible, no action required
ZB	Rupture Disk failure Set point 20 mbar	0.0010	0.9990	1	2	1	2	2	2	1		Negligible, no action required
ZD	Interlocked Shutdown Conveying failure	0.0010	0.9990	1	2	1	2	2	2	1		Negligible, no action required
ZE	Air Instrument Pressure Control failure Set point 50 mbar	0.0010	0.9990	1	2	1	2	2	2	1		Negligible, no action required
ZF	Interlocked Pressure Inside of Storage Bin Failure Set Point 60 mbar	0.0010	0.9990	1	2	1	2	2	2	1		Negligible, no action required

Table 9 Risk Level Summarization

Risk Level and Response required for risks identified		Summarize
1	Negligible, no action required	6
2	Acceptable risk: Control measures must be reviewed. Monitor for trends and patterns which may indicate increasing risk.	14
3	High risk Actions must be taken to mitigate risks.	7
4	Unacceptable risk: the operation must be stopped, and corrective action required reduce the risk immediately.	2

According to table 8 and 9 The researcher recommendation the control measure of 2 scenarios that were unacceptable risk levels (very high risk as level 4) and the high-risk level (level 3), there are 7 scenarios that require the address develop a risk reduction and mitigation plan, the example shown in table 10. And the MCC manufacturing management team has been implemented control measure in place with the management periodical review.

Table 10 Example of Risk Management Plan for Unacceptable Risk

Risk Management Plan (Risk reduction and control measure)						
Item	**Scenarios**	**Risk Level**	**Risk Reduction and Control Measure**	**Responsible**	**When**	**Follow up**
P6	Performing hot work (hot sparks) such as welding, cutting, milling, grinding (P6=H+I)					
H	Performing Hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits	4	1. Refresh training for operators to understand the hazards and preventive measures from dust explosion and review the training material of combustible dust fundamental with the training matrix revise and require annually refresh training of combustible dust fundamental training for all operator	Safety Officer	Quarterly Review	Internal Auditor
			1.1 Review the training material of combustible dust fundamental with the training matrix revise and require annually refresh training of combustible dust fundamental training for all operator	Safety Officer	Quarterly Review	Internal Auditor
			1.2 Revisit the topic of the annual training plan and orientation training program.	Human Resource and EHS Manager	Jan, 2023	Internal Auditor
			2.Hot work permit refresh training program	Safety Officer	Quarterly Review	Internal Auditor
			3. Field inspection training to compliance with the hot work safety precautions checklist in the process of permit to work approval for the job owner supervisor and the area owner supervisor and safety officers coaching program with the need to prepare the matter Comprehensive Job safety analysis before starting work. To ensure that the existing permit to work system in place as follow:	Safety Officer	Quarterly Review	Internal Auditor
			3.1. workplace observation and inspection before permitting the start of welding, cutting, milling, and grinding. it must be ensured that hazards such as remove dust deposit sources, surface cleaning are controlled. Elimination of fuel sources in a radius of 11 meters. 3.2. Fire watch man, fire banket, Fire extinguishers are available and ready for use in the hot work area. Responsible for remaining in the work area and watching for fires during duration of work and 1 hour after. The area will be monitored for 3 more hours by: security video cameras, routine rounds by security (every 30 minutes) 3.3. Certified fire watchers available with the hot work permit system training before permission hot work 3.4. Equipment inspection in good and safe condition with inspection tag ready to use. All cylinder vessel and regulators must be checked for availability.	Safety Committee	Quarterly Review	Internal Auditor
			4.Increase frequency of walk around to monitoring hot work performing to assess the compliance with the work permit system. And set the monthly audit by safety committee	Safety Committee	Quarterly Review	Internal Auditor

Step 6: Risk reduction credits compared before and after dust explosion hierarchy control implemented. Control measures must be periodical reviewed for 14 scenarios acceptable risk level in table 8 and 9. For 14 acceptable scenarios need to monitor for trends and patterns which may indicate increasing risk. The consequences of the event are estimated, again if none of the safeguards or layers of protection work. Next, the safeguards should be listed in the order that they would be expected to come into play during the scenario (including equipment names, numbers, interlock category, and other information, as appropriate). The process determined should then estimate the risk of the event, based upon the mitigated event frequency (i.e., the expected frequency of the consequences of the event, taking into consideration the frequency of the initiating event and the probability of failure of the intervening safeguards) and the unmitigated consequences. Based upon the risk assessment, the answer should conclude with either a statement to the effect that the risk is tolerable with the existing safeguards being adequate and no additional recommendations are required or a recommendation to reduce the risk to the required level of mitigation. The Auditability: A line of defense should be auditable in its ability to mitigate the risk of the hazard scenario. It should also be audited at an appropriate frequency. For lines of defense that rely on human action, the involved personnel

should be periodically re-trained and tested at an appropriate frequency. The site survey will be done, and the Risk reduction credits will be comparing with the existing control measure and risk management plan see the table 11.

Table 11 Safeguards or Lines of Defense for Risk reduction credits

Safeguard/Mitigation	PFD	Impact on Event Frequency (risk reduction credits)	Comments Assuming an adequate design basis and adequate inspection and maintenance procedures* ** Assuming adequate documentation, training and testing procedures***
Automatic explosion suppression system for process equipment	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	More quantitative analysis may support a lower PFD value for a specific system than the generic PFD provided.
Human response to an abnormal condition	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	
Human response to an abnormal condition with multiple indicators and/or sensors, and the operator has > 24 hours to accomplish the required response action	0.01 (1%)	Reduce by 2 orders of magnitude (2 credits)	
Personal protective equipment (PPE)	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	PPE is uniquely specified for the task and distinctly different from the standard PPE (safety shoes, overall, safety glasses, etc.)
Basic Process Control System (BPCS) (i.e. Process interlock)	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	Stop, prevent or mitigate the hazardous event. Can be credited as an IPL if not associated with the initiating event being considered. (See IEC 61508 (IEC, 1998) and IEC 61511 (IEC, 2001) for additional discussion.)**
SIL-1 safety interlock	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	
SIL-2 safety interlock	0.01 (1%)	Reduce by 2 orders of magnitude (2 credits)	
SIL-3 safety interlock	0.001 (0.1%)	Reduce by 3 orders of magnitude (3 credits)	
Flare stack	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	
Scrubber	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	
Blast enclosure	0.001 (0.1%)	Reduce by 3 orders of magnitude (3 credits)	Will reduce the frequency of large consequences of an explosion by confining blast and protecting equipment/buildings/etc.*
Shelter-in-place/evacuation	0.1 (10%)	Reduce by 1 order of magnitude (1 credit)	

Example: In evaluating the safeguards for the hazardous event scenario, identifies the following items:

1) Pressure monitoring sensor, in the storage bin triggers a process interlock at 60 mbar action of this interlock closes the MCC injection valves, stop the air flow to storage bin

2) High-high temperature safety interlock conveying. Based on the interlock design basis information, it is a SIL-3 interlock Action of this interlock close the control pressure air supply, show to conveying from spray dryer and transfer MCC from Storage bin to blending packing process, with the interlock close insolation vales and active explosion venting.

3) Risk reduction credits decision. Process interlock-one credit

4) SIL-3 safety interlock-tree credit

And the result of repeat of risk assessment with the probability and reliability calculated shown in table 12.

Table 12 Risk reduction credits 29 scenarios, probability, and reliability before and after improved.

Item	Scenarios	Before Implement Risk reduction and Control measure plan in 2017-2022			After Implemented Risk reduction and Control measure plan in 2022-2023		
		Probability of Failure on Demand (PFD)	Reliability	Risk Level	Probability of Failure on Demand (PFD)	Reliability	Risk Reduction Credit
P1	Ignition Source Indentified (P1= P4+P5+P6+P7+P8+P9)	0.7657	0.2343		0.4896	0.5104	
P4	Lightning strikes (P4=D+E)	0.2800	0.7200		0.1090	0.8910	
D	Lightning strike due to the ground wire or the ground rod was damaged by Insufficient PM. Do not maintained the connection point of the conductor to the ground is rusted or damaged from construction excavation work.	0.2000	0.8000	3	0.1000	0.9000	2
E	Insufficient Lightening protection installation	0.1000	0.9000	2	0.0100	0.9900	1
P5	Static Electricity Capacitive Spark Discharge (P5= F+G)	0.3194	0.6806		0.1090	0.8910	
F	Bounding /Grounding Damaged	0.1667	0.8333	2	0.1000	0.9000	1
G	Insufficient Bounding /Grounding Installation	0.1833	0.8167	2	0.1833	0.8167	1
P6	Performing hot work (hot sparks) such as welding, cutting, milling, grinding (P6=H+I)	0.4400	0.5600		0.1900	0.8100	
H	Performing with hot work (hot sparks) such as welding, cutting, milling, grinding without isolation/remove sources of dust deposits	0.3000	0.7000	4	0.1000	0.9000	3
I	Performing hot work (hot sparks) such as welding, cutting, milling, grinding not follow safety precaution of the hot work permit system	0.2000	0.8000	4	0.1000	0.9000	3
P7	Propagation of fire from the Transfer Blower (Positive Pressure Pneumatic Conveying conveying system) that carried the MCC product from the Spray dryer to the Storage Bin (P7=JK)	0.0089	0.9911		0.0001	0.9999	
J	Interlocked conveying systems failure to stop conveying at the pressure control set point 60 mbar	0.0667	0.9333	2	0.0010	0.9990	1
K	Explosion Isolation system lack of maintenance. (with a blocking gap greater than 0.2mm).	0.1333	0.8667	3	0.1000	0.9000	2

Table 12 (Continued)

Item	Scenarios	Before Implement Risk reduction and Control measure plan in 2017-2022			After Implemented Risk reduction and Control measure plan in 2022-2023		
		Probability of Failure on Demand (PFD)	Reliability	Risk Level	Probability of Failure on Demand (PFD)	Reliability	Risk Reduction Credit
P8	Self heating to ignition from electrical equipment at MIT, temperature 400 °C or MIE 200 mJ (P8=L+M)	0.0331	0.9669		0.1090	0.8910	
L	Explosion-proof electrical equipment was defected	0.0167	0.9833	2	0.1000	0.9000	1
M	Insufficient Explosion Proof Electrical	0.0167	0.9833	2	0.0100	0.9900	1
P9	Self-heating to ignition at MIT, temperature 400 °C or MIE 200 mJ from Instrument equipment that not qualified explosion proof (P9=N+O)	0.1090	0.8910		0.1090	0.8910	
N	Instrument equipment not qualified as Explosion proof due to equipment damaged	0.1000	0.9000	2	0.1000	0.9000	1
O	Insufficient Explosion proof Instrument	0.0100	0.9900	2	0.0100	0.9900	1
P2	Fire and Explosion Prevention Storage Bin Failure (P2=P10+P11)	0.6370	0.3630		0.4224	0.5776	
P10	Explosion Venting not activated according to Set Point at 100 mbar (P10= P+Q+R)	0.1350	0.8650		0.0120	0.9880	
P	Storage Bin Pressure Control Failure	0.0010	0.9990	2	0.0010	0.9990	1
Q	Explosion Venting Sensor Control Failure	0.0010	0.9990	2	0.0010	0.9990	1
R	Explosion Venting Pressure Relief Failure by improper selection of equipment, the equipment has small holes causing dust to accumulate inside of layer panel, causing to activating before the set point at 100 mbar. To damage the explosion panel and impact to shut down operation 8 hours for replace new set.	0.1333	0.8667	3	0.0100	0.9900	2
P11	The fire suppression system in the storage bin does not work as scheduled. (P11=P13+P14)	0.5803	0.4197		0.4154	0.5846	
P13	Temperature sensor failure (not activated at set point 150 °C) (P13=S+t)	0.1090	0.8910		0.1090	0.8910	
S	Temperature Indicator Failure	0.0100	0.9900	2	0.0100	0.9900	1
t	Temperature sensor Insufficient PM (not activated at set point 150 °C)	0.1000	0.9000	2	0.1000	0.9000	1
P14	Insufficient fire water pressure (P14=P15+P16)	0.5290	0.4710		0.3439	0.6561	
P15	Fire Pump performance test fails as required (P15=U+V)	0.2934	0.7066		0.1900	0.8100	
U	The Fire Pump performance test fails as required (the ratio between flow rate and pressure is less than 95%.) due to impeller equipment damaged by impact or corrosion	0.2000	0.8000	3	0.1000	0.9000	2
V	Insufficient PM not covered by the NFPA25 standard required.	0.1167	0.8833	3	0.1000	0.9000	2
P16	Insufficient fire water supply from the storage system (P16=W+X)	0.3334	0.6666		0.1900	0.8100	
W	Insufficient fire water supply due to malfunctioning water level control device	0.2000	0.8000	3	0.1000	0.9000	2
X	Insufficient fire water supply from suction pipe eccentric reducer insufficient designed	0.1667	0.8333	3	0.1000	0.9000	2

Table 12 (Continued)

Item	Scenarios	Before Implement Risk reduction and Control measure plan in 2017-2022			After Implemented Risk reduction and Control measure plan in 2022-2023		
		Probability of Failure on Demand (PFD)	Reliability	Risk Level	Probability of Failure on Demand (PFD)	Reliability	Risk Reduction Credit
P3	Dispersion of MCC Dust Particles (P3=Y+Z+P12)	0.1143	0.8857		0.1143	0.8857	
Y	Air purge Cleaning Failure (Normal operate 5-35 mbar)	0.0010	0.9990	2	0.0010	0.9990	1
Z	Equipment Repaired such as replacing the filter, replacing the measuring device inside storage bin	0.1000	0.9000	2	0.1000	0.9000	1
P12	Storage Bin Pressure Control System failure (P12= ZA+ZB+ZC+ZD+ZE+ZF)	0.0149	0.9851		0.0149	0.9851	
ZA	Air Purge Control system Interlocked process shut down failure (normal operate 5-35 mbar)	0.0010	0.9990	1	0.0010	0.9990	1
ZB	Rupture Disk failure Set point 20 mbar	0.0010	0.9990	1	0.0010	0.9990	1
ZC	Pressure Indicator/Pressure Transmitter failure	0.0100	0.9900	1	0.0100	0.9900	1
ZD	Interlocked Shutdown Conveying failure	0.0010	0.9990	1	0.0010	0.9990	1
ZE	Air Instrument Pressure Control failure Set point 50 mbar	0.0010	0.9990	1	0.0010	0.9990	1
ZF	Interlocked Pressure Inside of Storage Bin Failure Set Point 60 mbar	0.0010	0.9990	1	0.0010	0.9990	1

DISCUSSION & CONCLUSION

After the MCC manufacturing implemented of the risk reduction and control measure plan and reviewed the risk assessment result after improvement the control measure during June 2022-March 2023. There is always a tracking and inspection system for availability with site tour, audit and monitor for trends and patterns which may indicate increasing risk. The audit result was found that it meets the conditions of the safeguards or lines of defense for risk reduction credits see example in table 11 and layer of protection analysis (LOPA) of manufacturing microcrystalline cellulose are compliance with the control measure the result of risk reduction credit come from the dust explosion hierarchy control measure implemented as inherent safety principles (Abuswer et al., 2013) process designed layer of protection SIL 3 process safety control, this include the engineering, and administrative controls such as isolation vales to prevent fire propagation to next process, fire suppression system to prevent fire propagation, bounding/grounding to prevent electrostatic discharge, explosion proof electrical area classification compliance, explosion venting to release deflagration pressure to safe location. Including housekeeping/ dust removing, dust explosion foundation employees training and hot work permit to work system control measure. The result of after repeat risk assessment in the table 12 and compared probability, reliability credits 29 scenarios before and after improved risk management plan shown in figure 16 and 17 the top event of the dust explosion at dust explosion in storage bin of microcrystalline cellulose is represented by T, where T=ABCP1P2 P3 (which are element one the amount of oxygen in the air represented by the letter A, element two is MCC combustible dust represented by the letter B, element tree the confinement of dust cloud (in the Storage Bin) is represented by the letter C, element four ignition source is represented by the letter P1. element five dispersion of dust particles (MCC) is represented by the letter P3, and the researcher has further analyzed the part of element six fire suppression and explosion venting failure is fire suppression and explosion venting failure, represented by the letter P2. The probability P (T) is decrease from 0.0557 to 0.0236 and reliability increase from 0.9443 to 0.9764. The element ignition source (P1) there is a probability of occurrence decrease from 0.7657 to 0.4896. And reliability increase from 0.2343 0.5104. The element of fire suppression and explosion venting failure (P2) probability of occurrence decrease from 0.6370 to 0.4224 and Reliability increase from 0.3630 to 0.5776, The element of dispersion of MCC dust (dispersion of dust particles: P3) a probability of occurrence is slightly same before and after 0.1143 and Reliability 0.8857 and the result of risk level was reduction shown in the figure 18.

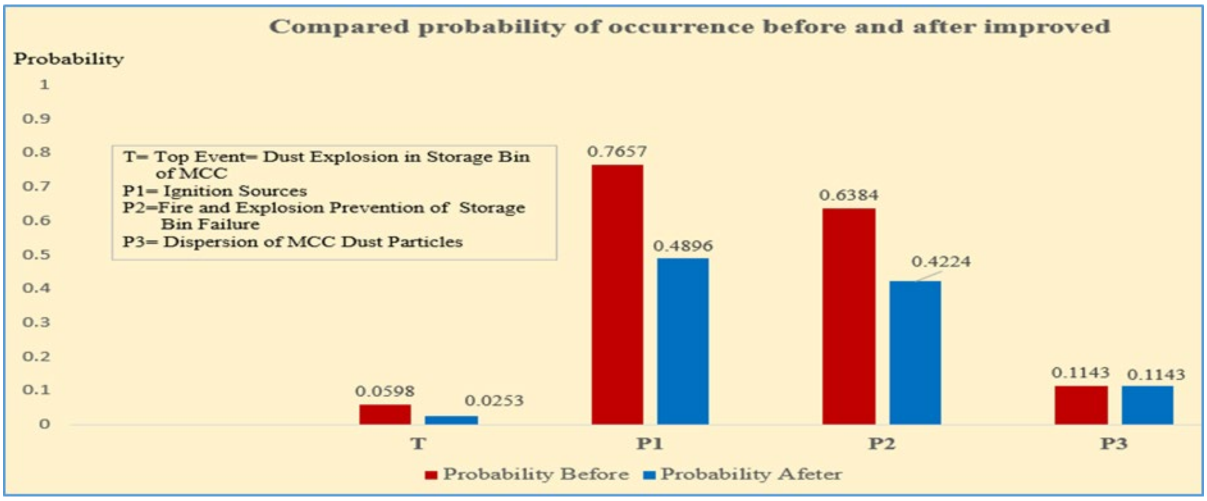

Figure 16 Probability of occurrence to compare before and after improved

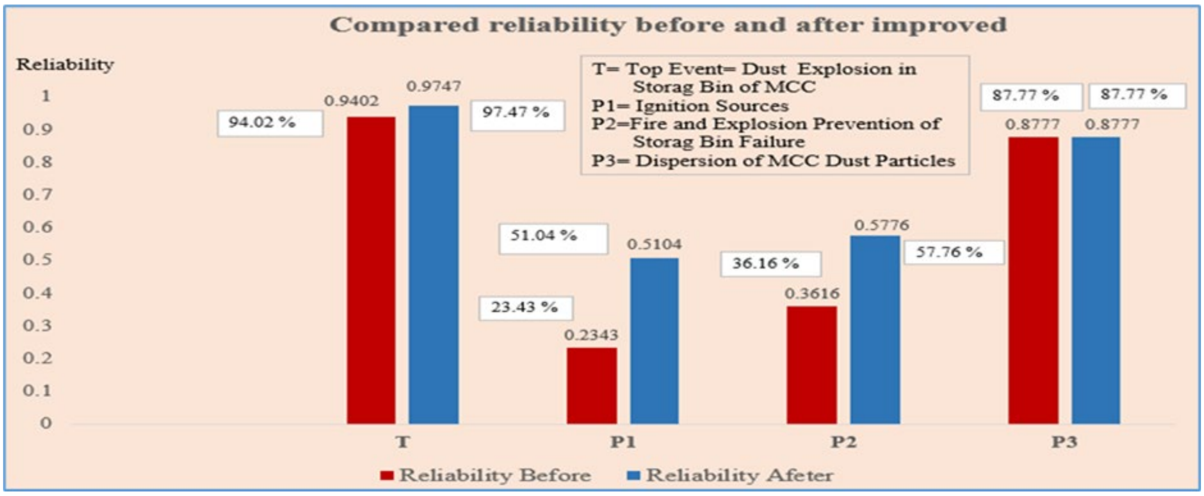

Figure 17 Reliability to compare before and after improved.

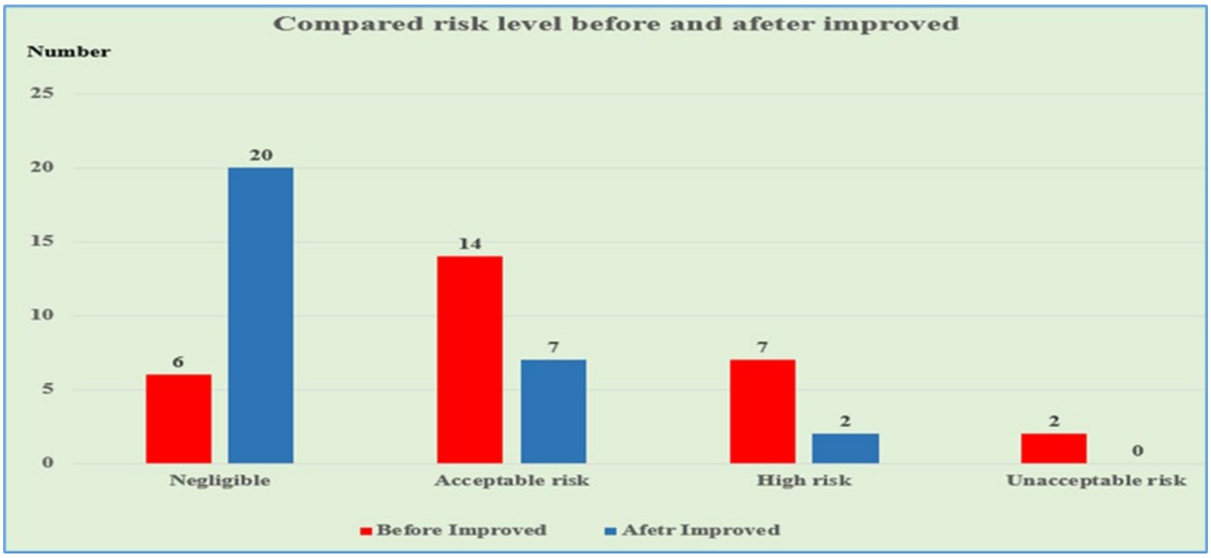

Figure 18 Risk level reduction to compare before and after improved.

The obvious advantage of Fault Tree Analysis (FTA) hazard identification is to find the frequency of more than one hazard or cause incident at the same time. That limitations in the HAZOP and What If hazard identification methods. FTA risk assessment results can be integrated with existing Process Hazard Analysis (PHA) risk assessments to increase hazard identification efficiency. And determine an appropriate risk management plan for the organization. The QRMF developed by Abuswer et al. (2013) can help prevent and mitigate dust and hybrid mixture explosions in the process industries and provide an optimal level of safety and risk management. The lesson learns for this studied the researcher has suggestions as below.

1) Hot work performing (hot sparks) such as welding, cutting, milling, grinding even though there is supervision to follow the system for permission to work with spark heat but the quality of the inspection should be increased as before the work is allowed to conduct a comprehensive job safety analysis before starting work. Including increasing the frequency of inspections. System for monitoring and evaluating the compliance with the work permit application system of those involved.

2) To review critical equipment list with a labeling and tag number. Need to be install into the maintenance preventive maintenance tracking system, review critical equipment especially the entry in fire and dust explosion prevention system and critical process control system related to interlocked machine shutdown to be covered by the interlocked list with the functional verification periodically.

3) To review the spare part list of critical equipment to determine the appropriate budget for purchasing critical equipment to have a spare part ready to be replaced.

4) Need to verify a system to ensure that electrical equipment and instrument measuring equipment are installed comprehensively and comply with the hazard area classification.

5) The organization has designed and approved the installation of an additional fire pumps, with total of two fire pumps run one stand by one, there must be a system for monitoring and evaluating the implementation of the preventive maintenance plan, of the service provider to comply with NFPA 25 (NFPA 25, 2020) to ensure that fire pumps are always available for use and reliability compliance as required

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