DUST HAZARD ANALYSIS (DHA): THE STEPPINGSTONE TO EFFECTIVE COMBUSTIBLE POWDER RISK CONTROL

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1 ABSTRACT

In India numerous chemical manufacturers handle and store combustible powders as part of their operations, including highly ignition sensitive and/or explosive powders. While most organizations are aware of the hazards associated with handling of combustible powders, a lack of regulatory framework within the country has led to a wide range of combustible dust handling practices within the country ranging from a complete absence of a formal program, to an extremely well defined and sustainable combustible dust handling program that enables risk-based decision making. The paper proposes the idea that an appropriate and effective DHA can provide an organization with the required inputs to help build a strong and sustainable combustible dust hazard management program. This paper discusses three different methodologies for conducting a Dust Hazard Analysis (DHA) with increasing levels of complexity. and presents three case-studies highlighting the differences between the methodologies and their outcomes. The paper also broadly classifies the organizations within three maturity levels based on their dust hazard management programs and proposes interventions for an effective way forward in the journey to build strong, sustainable, and continuously improving combustible dust hazard management programs.

2 INTRODUCTION

Fifty-Three (53) explosions and One-Hundred and Sixty-Three (163) fires resulting in Sixty-Nine (69) fatalities and Two Hundred and Fourteen (214) injuries were recorded (worldwide) in 2021 [1]. The potential for catastrophic consequences from dust explosions have been extensively investigated and recorded. Methods for prevention and mitigation are easily accessible but incidents keep occurring. While interacting with front-line personnel, we have found that such incidents often occur due to a lack of awareness of combustible dust hazards which can result in ineffective hazard identification, risk analysis and risk management.

In the United States of America, NFPA 652 (2019) requires that an owner/operator of any facility handling combustible powder shall complete a Dust Hazard Analysis (DHA), before the deadline of September 7, 2020[2]. The standard provides two options to conduct the DHA, a prescriptive approach which requires compliance with the guidance provided in NFPA 652, and a performance-based approach which uses a risk analysis based methodology. The outcome of either of these analyses shall be formally documented and must be reviewed and updated every five (5) years.

In the European Union (EU), the DIRECTIVE 1999/92/EC requires every employer to provide protection against explosions (resulting from flammable substances in the form of gases, vapors, mists or dusts), by taking technical and/or organizational measures appropriate to the nature of the operation, in order of priority and in accordance with the following basic principles:

1. the prevention of the formation of explosive atmospheres, or where the nature of the activity does not allow that,
2. the avoidance of the ignition of explosive atmospheres, and
3. the mitigation of the detrimental effects of an explosion so as to ensure the health and safety of workers.

To fulfill the aforementioned obligations the employer shall assess the specific risks arising from explosive atmospheres, taking into account at least:

1. the likelihood that explosive atmospheres will occur and
2. their persistence,
3. the likelihood that ignition sources, including electrostatic discharges, will be present and become active and effective,
4. the installations, substances used, processes, and their possible interactions,
5. the scale of the anticipated effects.

The employer shall document the risk assessment in a formal document commonly referred to as Explosion Protection Document (EPD) [3]

Regulatory framework such as the ones present in the EU and USA are not available in India. In practice, India also uses NFPA and ATEX EN combustible dust standards, but currently there are no official Indian regulations formally recognizing, adopting or modifying those standards. According to Paul Amyotte and Faisal Khan "Although India also has promulgated some of its own fire protection standards for different types of industrial facilities, it is not clear if there is much emphasis or detail on dust explosion protection in those standard" [4]. This results in many operators in India operating without a specific combustible dust risk assessment and a formal program for management of combustible dust hazards due to which an operator may be vulnerable to higher risks than tolerable due to one or combination of the following reasons:

1. Inadequate hazard identification
    I. Lack of appropriate testing data (hazard characterization)
        i. All combustible powders not tested for combustibility and/or explosibility
        ii. All required tests for combustibility and ignition sensitivity not performed
        iii. Tests not performed to recognized and accepted standards
        iv. Representative worst-case samples not tested
    II. Inadequate hazard identification and risk analysis exercise
        i. Incomplete identification of fuel-air mixtures during normal and/or abnormal operations
        ii. Incomplete and/or incorrect identification and characterization of ignition sources
        iii. Inadequate number of barriers provided
2. Inadequate risk management

    i. Inadequately designed barriers provided
    ii. Inadequately maintained barriers
    iii. Inadequate training and competence
    iv. Inadequate operating procedures, work permit system, and change management
    v. Inadequate emergency response

This paper attempts to highlight the importance of having a robust combustible dust hazard management program and how a Dust Hazard Analysis (DHA) can act as a gateway to building a comprehensive and robust dust hazard management program.

3 DUST HAZARD ANALYSIS (DHA) METHODOLOGIES

The section details the different types of Dust Hazard Analysis (DHA) methodologies (in increasing order of complexity), their applicability, advantages, and limitations.

3.1 Checklist Analysis

A checklist analysis typically consists of a checklist being completed by skilled personnel to analyze the gaps within the system. A checklist created out of requirements from NFPA 652 [2] can be an effective way of identifying gaps in Dust Explosion Prevention and Mitigation strategies and Combustible Dust Hazard Management Systems.

A checklist created out of the requirements of NFPA 652 will consist of the following areas of analysis:

1. Management Systems
    I. Operating Procedures
    II. Housekeeping
    III. Hot Work
    IV. Personal Protective Equipment (PPE)
    V. Inspection, Testing and Preventive Maintenance (ITPM)
    VI. Training and Hazard Awareness
    VII. Contractor Management
    VIII. Emergency Response and Planning
    IX. Incident Investigation
    X. Management of Change
    XI. Documentation Retention
    XII. Management System Review
    XIII. Employee Participation
2. Hazard Management: Mitigation and Prevention
    I. Building Design
    II. Equipment Design
    III. Ignition Source Control
    IV. Dust Control
    V. Explosion Prevention/Protection
    VI. Fire Protection

More advanced checklists also incorporate the requirements of other combustible dust standards such as NFPA 77, NFPA, 68, NFPA 69 and commodity specific standards such as NFPA 61, NFPA 484, NFPA 655 and NFPA 664.

3.1.1 Pre-Requisites for Checklist Analysis

The following is required to effectively perform a checklist analysis:

1. List of Combustible Powders
2. Powder Testing Results for Combustible Powders OR dust explosion data from a public database such as GESTIS DUST EX [5]
3. Process Description
4. Equipment Design and Operation Data
5. Skilled Analyst

3.1.2 Advantages of a Checklist Analysis

1. Less time and resource intensive
2. Provides an analysis of management practices of the area under analysis
3. Scope of the analysis is not dependent on the individual's skills and/or competence

3.1.3 Limitations of the Checklist Analysis

1. Does not allow for risk-based decision making which can lead to cost intensive outcomes or insufficient risk controls
2. Might not seek consensus from a multi-disciplinary team for decision making
3. Does not consider evaluate specific fire and explosion scenarios

3.2 Scenario based Qualitative Analysis

A scenario based qualitative analysis has been detailed in multiple texts [4], [6]. In a scenario based qualitative analysis, the team aims to qualitatively evaluate the risk with specific fire and explosion scenarios associated with every equipment and operation. The analysis is intended to be performed by a multi-disciplinary team and shall be led by an experienced facilitator. This type of analysis is very much in line with requirements of the ATEX requirements [3] and takes into consideration all the considerations listed in Section 2.

3.2.1 Pre-Requisites for Scenario based Qualitative Analysis

The following is required to effectively conduct a scenario based Qualitative Analysis.

1. A multi-disciplinary team consisting of personnel from Operations, Mechanical, Process Engineering, Process Safety and any other relevant departments
2. A skilled facilitator with extensive knowledge and experience of workshop leadership
3. A combustible dust hazard expert
4. Process design documentation (including fire/explosion mitigation systems)
5. Operating procedures
6. ITPM procedures and records
7. Combustible powder testing data including consequence and ignition sensitivity analysis
8. Area classification diagrams
9. Equipment layout

3.2.2 Advantages of a Scenario based Qualitative Analysis

1. Enables a scenario-based evaluation which when applied by a skilled facilitator and team, can yield a more comprehensive analysis as compared to the checklist analysis
2. Enables consensus driven decision making through a competent team
3. Enables risk-based decision making resulting in scenario specific recommendations. This enables better acceptability of the recommendation by the recommendation owner.

3.2.3 Limitations of a Scenario Based Qualitative Analysis

1. Time and resource intensive
2. Output highly dependent on the competence and experience of the analysis team
3. Risk ranking can be subjective resulting in inconsistent results

3.3 Semi-Quantitative Dust Hazard Analysis

A semi-quantitative Dust Hazard Analysis (DHA) is a scenario-based analysis in which the risk is evaluated by evaluating the consequence severity qualitatively and the likelihood is evaluated quantitatively in a LOPA style assessment. The methodology for such an analysis has been detailed in the CCPS Book [6].

The methodology allows for a more granular likelihood estimation by allowing a quantitative estimation of probability of ignition, probability of presence of a combustible atmosphere, probability of presence of personnel enabling better risk-based decision making. The methodology also requires rigorous evaluation of the Independent Protection Layers (IPLs) to differentiate between IPLs and safeguards.

3.3.1 Pre-Requisites for a Semi-Quantitative Analysis

The following is required to effectively conduct a Semi-Quantitative Dust Hazard Analysis:

1. A multi-disciplinary team consisting of personnel from Operations, Mechanical, Process Engineering, Process Safety and any other relevant departments
2. A skilled facilitator with extensive knowledge and experience of workshop leadership, risk assessment and IPL evaluation
3. A combustible dust hazard expert
4. Process design documentation (including fire/explosion mitigation systems)
5. Operating procedures
6. ITPM procedures and records
7. Combustible powder testing data including consequence and ignition sensitivity analysis
8. Area classification diagrams
9. Equipment layout

3.3.2 Advantages of Semi-Quantitative DHA

In addition to the advantages of the scenario-based DHA methodology (Section 3.2.2) a semi-quantitative DHA enables more granular risk analysis and enables a more consistent risk evaluation.

3.3.3 Limitations of Semi-Quantitative DHA

In addition to the disadvantages of the scenario based DHA methodology (Section 3.3.3) a semi-quantitative risk analysis can be more resource intensive to complete the analysis. This methodology also requires a certain degree of expertise in risk analysis methodologies and IPL evaluation to be applied effectively.

3.4 Comparison with HAZOP and other Traditional Risk Assessment Methodologies

While traditional risk assessment methodologies have been used for risk assessment of combustible dust hazards, they can result in sub-optimal risk evaluation if the risk analysis team is not skilled in combustible dust hazard evaluation. A primary reason for this is these methodologies are not designed to evaluate the specific challenge with combustible dust hazards.The evaluation of likelihood of multiple ignition sources for a combustible dust atmosphere as a single scenario, can lead to confusion for the hazard evaluation team and double counting of IPLs for different types of ignition sources.

4 CASE-STUDY

The case-studies show below highlight the key differences between the proposed methodologies.

4.1 Case Study-1

The scenario considered for the first demonstration is transfer of a combustible powder with MIE of 30mJ to a silo.

4.1.1 Checklist Analysis [Appendix A.1.1]

In a checklist analysis, the analyst would be expected to refer to the different sections of the checklist developed from the NFPA 652 guidance. When referring to the guidance for equipment design in Section 9.7.3 of the NFPA 652, a recommendation to provide a means of explosion prevention/protection will be recommended. Through the guidance on ignition source control, the following recommendations will be required:

1. Installation of electrical equipment compliant with the zone classification of the silo will be required as per section 9.4.6.
2. Appropriate grounding and bonding of the conductive components of the silo will be required as per section 9.4.7.1.3.

It must be noted that as per section 9.4.7.2.1 and 9.4.7.2.2, since the MIE of the material being transferred to the silo is >20mJ, particulate transport rates need not be limited as per the guidance provided in section 9.4.7.2.3.

4.1.2 Scenario based DHA [Appendix A.2.1]

For the purpose of demonstration, only the cases of ignition through electrostatic discharge were considered.

The analysis requires a recommendation to mitigate the Medium risk due to possibility of spark discharge, to which a recommendation to provide inerting (or any other explosion protection/prevention method) to the silo can be made by the team based on ease of implementation, which is in line with the recommendations from the Checklist based analysis.

However, the significant difference between the two approaches is that the rationale for the recommendation can be visualized with the scenario-based methodology. This enables better recommendation ownership and acceptability.

4.1.3 Semi-Quantitative DHA [Appendix A.3.1]

For the purpose of demonstration, only the cases of ignition through electrostatic discharge were considered.

Similar to a LOPA, the analysis requires the team to determine a Target Mitigated Event Likelihood (TMEL) for an event. The methodology then analyzes hazardous scenarios while accounting for the likelihood of the initiating event, conditional modifiers such as probability of ignition (not every powder is equally ignition sensitive), probability of formation of a combustible cloud, and probability of presence of personnel.

When the scenario of ignition through spark discharge is evaluated, a risk gap of 1/100 year is obtained which requires a SIL-2 equivalent inerting system or a dust explosion venting system with appropriate isolation between downstream and upstream system.

The evaluation of the cone discharge scenario also results in a risk gap of 1/100 year, which requires the reduction of transfer velocities to the silo in accordance with Section

9.7.4.2.3 of NFPA 652 or implementation of any of the aforementioned recommendations.

4.2 Case Study-2

The scenario considered for the second case is transfer of a combustible powder with MIE of 3mJ to a silo.

4.2.1 Checklist Analysis [Appendix A.1.2]

A checklist analysis will result in identical results as those obtained in Case Study-1 [Section], with the additional recommendation to perform a rate-controlled addition of the silo in accordance with Section 9.7.4.2.3 of NFPA 652.

4.2.2 Scenario based DHA [Appendix A.2.2]

The analysis requires a recommendation to mitigate the Medium risk due to possibility of spark discharge, to which a recommendation to provide inerting to the silo can be made, which is in line with the recommendations from the Checklist based analysis.

The risk due to the cone discharge is evaluated as high and a recommendation to reduce the transfer velocity and to provide inerting to the silo can be made to reduce the risk which is in line with the requirements of the checklist-based analysis.

4.2.3 Semi-Quantitative DHA [Appendix A.3.2]

The analysis determines a risk gap of 1/1000 years for the spark discharge scenario when grounding and bonding is provided. Based on the risk criteria in this example, in order to mitigate the risk to a tolerable level, inerting or explosion venting alone as determined through the checklist and scenario based analysis may not enough. The team could recommend to provide explosion venting and isolation in addition to inerting or inerting combined with an earth monitoring system to stop addition of the powder to the silo when earthing is lost (at least on of them needs to be SIL-2).

The analysis determined a risk gap of 1/10000 years for the cone discharge scenario. Based on the risk criteria in this example, in order to mitigate the risk to a tolerable level, reduction of the particulate velocity may not be sufficient unless executed in an inherently safe manner such that a failure mode which would allow the velocity to increase beyond the permissible limits would not be possible. Therefore, additional recommendations to provide explosion venting and isolation along with inerting may be required..

4.3 Case Study-3

The scenario considered for the third case is the. transfer of a combustible powder with MIE of 500mJ to a silo.

4.3.1 Checklist Analysis [Appendix A.1.3]

A checklist analysis for this scenario would yield identical results to that obtained for Case Study-1 (Section 4.1.1) including the recommendation to provide an explosion protection/prevention measure in accordance with Section 9.7.3.2 of NFPA 652.

4.3.2 Scenario Based DHA [Appendix A.2.3]

A scenario-based DHA performed with a qualitative risk ranking concludes that an explosion protection/prevention is not required for the spark discharge or the cone discharge scenario which is contradictory to the outcome of the checklist analysis.

4.3.3 Semi-Quantitative DHA [Appendix A.3.3]

A semi-quantitative risk-based DHA concludes that a risk gap of 1/10 year exists for spark discharge scenario after accounting for the grounding and bonding and the difficulty of igniting a powder with MIE of 500mJ with a spark discharge. However, this gap can easily be bridged with an independent and effective administrative control and still might not require the provision of an explosion protection/prevention measure as proposed by the checklist analysis.

5 DISCUSSION

Three methodologies for performing DHAs with increasing resource requirements and decreasing ease of application were discussed along with three different cases to demonstrate the difference in outcomes. The three methodologies can produce different outcomes based on the specific scenarios being evaluated and these outcomes can be more or less conservative.

The authors of this paper try to classify the organizations handling combustible dust into three (3) categories and propose a way forward to build and/or sustain a robust combustible dust program.

5.1 No Dust Hazard Management

An organization that has no formal means of managing combustible dust hazards, a DHA has never been performed for the facility and the awareness and competence around combustible dust hazards in the organization is very low.

5.1.1 Proposed Intervention

The organization shall start with a checklist based dust hazards analysis to identify significant gaps within the systems and equipment design. Once the results from the assessment are obtained the organization shall aim to implement as many of the recommendations as possible and to build systems to manage the hazards associated with combustible dust.

The organization shall then manage the acceptance and rejection of the remainder of hazards through a scenario based DHA. The analysis will enable the team to take risk based decisions.

5.2 Informal Dust Hazard Management

An organization that has some means of managing combustible dust hazards such as a PSM program but not a dedicated combustible dust hazard management program, a scenario-based DHA has never been performed for the facility and the awareness and competence around combustible dust hazards in the organization is not very high.

5.2.1 Proposed Intervention

The organization shall start with a checklist based dust hazards analysis to assess the robustness of their systems against the Recognized and Generally Acceptable Good Practices (RAGAGEP). The results from the checklist assessment shall act as an input for the scenario based DHA to help identify hazardous scenarios and debate the robustness of the safeguards. The scenario based DHA can then be used to make risk based decision on the implementation of recommendations from the checklist analysis or evaluate if additional recommendations are required to mitigate the risk.

5.3 Formal Dust Hazard Management

An organization that has a formal combustible dust hazards management program and has performed a baseline scenario-based DHA for identifying hazards and risks associated with dust fires and explosions. The awareness and competence of combustible dust hazards is generally high in the organization.

5.3.1 Proposed Intervention

The organization shall start with a checklist-based dust hazards analysis to assess the robustness of their systems against the Recognized and Generally Acceptable Good Practices (RAGAGEP). The results from the checklist assessment shall act as an input for the semi-quantitative DHA. The aim of this DHA shall be to separate the safeguards from IPLs , determine the risk gaps, and to evaluate the validity of the recommendations made during the checklist analysis. Appropriate recommendations shall be made to bridge the gaps identified by proposing new IPLs or improving the reliability of existing IPLs.

6 CONCLUSIONS

Three methodologies for performing DHAs with increasing resource requirements and decreasing ease of application were discussed along with three different cases to demonstrate the difference in outcomes. The three methodologies can produce different outcomes based on the specific scenarios being evaluated and these outcomes can be more or less conservative.

Interventions were proposed for organizations among three different levels of maturity in their combustible dust hazard management program with an emphasis on how a DHA can act as effective means of evaluating hazardous scenarios, robustness of system and making risk-based decisions. The outcome of the DHA can then be used to embark on a journey of continuous improvement to strengthen the dust hazard management program within the organization.

7 REFERENCES

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Appendix A. Case Study Outputs

A.1. Checklist Analysis

A.1.1. Case-1

Addition of an Explosible Powder with 30mJ MIE to a Silo

Operation and Equipment Specific Requirements as per NFPA 652

1	Silo shall be provided with explosion protection through one of the following methods: 1. Inertization (in accordance with NFPA 69) 2. Deflagration Venting (in accordance with NFPA 68) 3. Deflagration pressure containment (in accordance with NFPA 68) 4. Deflagration Suppression system (in accordance wirh NFPA 69) 5. Dilution of the combustible dust with a non-combustible dust
2	Electrical equipment inside the silo shall be as per zone classification
3	Bonding and grounding with a resistance of less than 1.0 × 10^6 ohms to ground shall be provided for conductive components.
4	Material in silos and other large storage piles of particulates prone to self-heating shall be managed to control self-heating or have self-heating detection provisions
5	Where a self-heating hazard is identified, provisions shall be in place for managing the consequences of self-heating in storage silos or bins.
6	Isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation between connected equipment

A.1.2. Case-2

Addition of an Explosible Powder with 3mJ MIE to a Silo

Operation and Equipment Specific Requirements as per NFPA 652

1	Silo shall be provided with explosion protection through one of the following methods: 1. Inertization (in accordance with NFPA 69) 2. Deflagration Venting (in accordance with NFPA 68) 3. Deflagration pressure containment (in accordance with NFPA 68) 4. Deflagration Suppression system (in accordance wirh NFPA 69) 5. Dilution of the combustible dust with a non-combustible dust
2	Electrical equipment inside the silo shall be as per zone classification
3	Bonding and grounding with a resistance of less than 1.0 × 10^6 ohms to ground shall be provided for conductive components.
4	Material in silos and other large storage piles of particulates prone to self-heating shall be managed to control self-heating or have self-heating detection provisions
5	Where a self-heating hazard is identified, provisions shall be in place for managing the consequences of self-heating in storage silos or bins.
6	Isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation between connected equipment
7	Maximum particulate transport rates provided in NFPA 652 shall be followed

A.1.3. Case-3

Addition of an Explosible Powder with 500mJ MIE to a Silo

Operation and Equipment Specific Requirements as per NFPA 652

1	Silo shall be provided with explosion protection through one of the following methods: 1. Inertization (in accordance with NFPA 69) 2. Deflagration Venting (in accordance with NFPA 68) 3. Deflagration pressure containment (in accordance with NFPA 68) 4. Deflagration Suppression system (in accordance wirh NFPA 69) 5. Dilution of the combustible dust with a non-combustible dust
2	Electrical equipment inside the silo shall be as per zone classification
3	Bonding and grounding with a resistance of less than 1.0 × 10^6 ohms to ground shall be provided for conductive components.
4	Material in silos and other large storage piles of particulates prone to self-heating shall be managed to control self-heating or have self-heating detection provisions
5	Where a self-heating hazard is identified, provisions shall be in place for managing the consequences of self-heating in storage silos or bins.
6	Isolation devices shall be provided in accordance with NFPA 69 to prevent deflagration propagation between connected equipment

A.2. Scenario Based DHA

A.2.1. Case-1

	Flammable Atmosphere			Ignition Source							
S. No.	**Operation/Activity Description**	**Type**	**Consequence**	**Type**	**Description**	**Ignition Likelihood**	**Initial Risk**	**Safeguards**	**Current Risk**	**Recommedations**	**Residual Risk**
1	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Spark	Spark discharge between conductive elements	Likely	High	Grounding and bonding is provided to the silo	Medium	Provide inertization to the silo in accordance with NFPA 69	Low
2	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Cone	Cone discharge due to slow dissipation of charges to the ground	Unlikely	Low	None	Low	None	Low

A.2.2. Case-2

	Flammable Atmosphere			Ignition Source							
S. No.	**Operation/Activity Description**	**Type**	**Consequence**	**Type**	**Description**	**Likelihood of Ignition**	**Initial Risk**	**Safeguards**	**Current Risk**	**Recommedations**	**Residual Risk**
1	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Spark	Spark discharge between conductive elements	Certain	High	Grounding and bonding is provided to the silo	Medium	1. Provide inertization to the silo in accordance with NFPA 69	Low
2	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Cone	Cone discharge due to slow dissipation of charges to the ground	Very Likely	High	None	High	1. Provide inertization to the silo in accordance with NFPA 69 2. Reduce the transfer velocity of particles to the silo in accordance with NFPA 652	Low

A.2.3. Case-3

	Flammable Atmosphere			Ignition Source							
S. No.	**Operation/Activity Description**	**Type**	**Consequence**	**Type**	**Description**	**Ignition Likelihood**	**Initial Risk**	**Safeguards**	**Current Risk**	**Recommedations**	**Residual Risk**
1	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Spark	Spark discharge between conductive elements	Unlikely	Low	Grounding and bonding is provided to the silo	Low		Low
2	Explosible atmosphere inside the silo due to the transfer	Continious	Dust Explosion inside the silo due to ignition source resulting in multiple fatalities	Static Discharge - Cone	Cone discharge due to slow dissipation of charges to the ground	Impossible	Low		Low		Low

A.3. Semi-Quantitative DHA

A.3.1. Case-1

	Flammable Atmosphere		Ignition Source						Conditional Modifiers				IPLs										
S.No.	Description	Type	Description	Type	Cause	IEL	Consequence	TMEL	Likelihood of Ignition	Likelihood of Combustible Atmosphere	Likelihood of Presence	Safeguards	IPL-1	RRF	IPL-2	RRF	IPL-3	RRF	MEL-1	Req. RRF	Recommendations	RRF	MEL-2
1	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Spark Discharge	Generation and accumulation of static charges on conductive elements due to powder transfer	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	0.1	1	0.1	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	0.1		1		1	1.00E-03	1.00E+02	1. Provide inertization to the silo (SIL-2 equivalent system) OR Provide dust explosion vent in accordance with NFPA 68 with isolation of upstream system	0.01	1.00E-05
2	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Cone Discharge	Normal Operation	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	0.01	1	0.1			1		1		1	1.00E-03	1.00E+02	1. Reduce the speed of transfer to Silo to be within the limits specified in NFPA 652	0.01	1.00E-05

A.3.2. Case-2

	Flammable Atmosphere		Ignition Source						Conditional Modifiers				IPLs										
S.No.	Description	Type	Description	Type	Cause	IEL	Consequence	TMEL	Likelihood of Ignition	Likelihood of Combustible Atmosphere	Likelihood of Presence	Safeguards	IPL-1	RRF	IPL-2	RRF	IPL-3	RRF	MEL-1	Req. RRF	Recommendations	RRF	MEL-2
1	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Spark Discharge	Generation and accumulation of static charges on conductive elements due to powder transfer	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	1	1	0.1	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	0.1		1		1	1.00E-02	1.00E+03	1. Provide inertization to the silo (SIL-2 equivalent system) [RRF-10] 2. Provide dust explosion vent in accordance with NFPA 68 with isolation of upstream system [RRF-100]	0.001	1.00E-05
2	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Cone Discharge	Normal operation	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	1	1	0.1			1		1		1	1.00E-01	1.00E+04	1. Reduce the speed of transfer to Silo to be within the limits specified in NFPA 652 [RRF-10] 2. Provide inertization to the silo (SIL-2 equivalent system) [RRF-10] 3. Provide dust explosion vent in accordance with NFPA 68 with isolation of upstream system [RRF-100]	0.0001	1.00E-05

A.3.3. Case-3

	Flammable Atmosphere		Ignition Source						Conditional Modifiers				IPLs										
S.No.	Description	Type	Description	Type	Cause	IEL	Consequence	TMEL	Likelihood of Ignition	Likelihood of Combustible Atmosphere	Likelihood of Presence	Safeguards	IPL-1	RRF	IPL-2	RRF	IPL-3	RRF	MEL-1	Req. RRF	Recommendations	RRF	MEL-2
1	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Spark Discharge	Generation and accumulation of static charges on conductive elements due to powder transfer	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	0.01	1	0.1	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	1. Grounding and Bonding is provided to all conductive components of the silo, effectiveness is periodically verified through resistance testing program [RRF-10]	0.1		1		1	1.00E-04	1.00E+01	1. Periodic inspection and resistance testing of the grounding and bonding connections to the silo shall be performed independent of the periodic ITPM for the grounding and bonding connections. [RRF-10]	0.1	1.00E-05
2	Continious Presence of combustible dust inside the silo during unloading operation	Continious	Spark discharge between two ungrounded conductive elements	Cone Discharge	Normal Operation	1	Dust explosion inside the silo resulting in multiple fatalities	1.00E-05	0.0001	1	0.1			1		1		1	1.00E-05	1.00E+00		1	1.00E-05