Birthday Cake Analogy
Outline

- Combustible Dust Hazards – Owner/Operator Responsibility
- DHA Requirements in NFPA Standards
- Preparing for your DHA
- Performing your DHA
- Mitigation Strategies
- Reporting Findings
- Example DHA
Combustible Dust Hazards – Owner/Operator Responsibility

1. Determining the combustibility and explosibility hazards of materials
2. Identifying and assessing any fire, flash fire, and explosion hazards
3. Managing the identified fire, flash fire, and explosion hazards
4. Communicating the hazards to the affected personnel

1NFPA 652 §4.1
DHA Requirements in NFPA Standards

• Criteria
  – The DHA shall evaluate the fire, deflagration, and explosion hazards and provide recommendations to manage the hazards

• Qualifications
  – The DHA shall be performed or led by a qualified person

• Documentation
  – The results of the DHA review shall be documented, including any necessary action items requiring change to the process materials, physical process, process operations, or facilities associated with the process.

1NFPA 652 §7.2
DHA Requirements in NFPA Standards

• NFPA 652 requires a DHA to be performed:¹
  – For all new processes and facility compartments
  – The DHA shall be reviewed and updated at least every 5 years

¹NFPA 652 §7.1
Methodology\textsuperscript{1}

• The DHA shall include the following:
  1. Identification and evaluation of the process or facility areas where fire, flash fire, and explosion hazards exist
  2. Where such a hazard exists, identification and evaluation of specific fire and deflagration scenarios shall include the following:
     – Identification of safe operating ranges
     – Identification of the safeguards that are in place to manage fire, deflagration, and explosion events
     – Recommendation of additional safeguards where warranted, including a plan for implementation

\textsuperscript{1}NFPA 652 §7.3
Preparing for a DHA
PREPARATION

“By failing to prepare you are preparing to fail.”

Benjamin Franklin
Preparing for a DHA

• Select Prescriptive DHA versus Risk-Based DHA
• Gather Process Safety Information
• Select hazard assessment methodology(ies)
• Assemble a team
Prescriptive Approach versus Risk-Based Approach

• A Prescriptive DHA only considers hazards, while a Risk-Based DHA considers both the hazards and the consequence
• A Prescriptive DHA can be more conservative by nature than a Risk-Based DHA
• A Risk-Based DHA requires more effort but allows greater flexibility in process design and hazard mitigation and ranks the most significant hazards

Image from Chemical Engineering Progress, p. 34 (2009)
Gather Process Safety Information

- P&IDs
- Energy and Mass Balance Tables
- Process Flow Diagrams
- Equipment layouts
- Existing Area Electrical Classifications
- Equipment Operation and Maintenance manuals
- Documentation on fire and explosion protection systems
- Control systems, alarms, and safety interlocks
- Information on past incidents
Hazard Identification Methodologies

- Checklist Analysis
- What-if Analysis
- Hazard and Operability Analysis (HAZOP)
- Failure Modes and Effect Analysis (FMEA)
- Combinations of multiple hazard identification methodologies
Checklist Analysis

• List of items or steps in a process
• May provide a basis for a basic evaluation
• Can vary in complexity and scope
• Can be used to standardize protection across different facilities

This Photo by Unknown Author is licensed under CC BY
# Example Checklist – NFPA 61

<table>
<thead>
<tr>
<th>COMBUSTIBLE DUST CHECKLIST</th>
<th>Expectation Compliance</th>
<th>Comments/Actions</th>
<th>Responsible</th>
<th>Date Due</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Date:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5.0 DRY SOLID PRODUCT MOVEMENT AND STORAGE (GENERAL)</strong></td>
<td>Yes</td>
<td>No</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>5.1 Are receiving systems prior to the leg provided with magnetic protection, or are other systems installed/provided for tramp materials before processing equipment (e.g., hammer mills, grinders, and pulverizers)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2 Is the whole process dusttight?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.3 Are delivery vehicles (such as trucks and railcars) grounded before discharge?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.4 Where flexible connections are employed, are they appropriately grounded and bonded?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5 Are ducting and flexible connections dusttight and able to resist the pressure and heat increase of a deflagration when associated with venting, isolation, or suppression systems?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.6 Where explosion vents are applied, is the vent sizing design basis on record and is the flame ball trajectory verified as safe by a qualified person?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.7 Have there been any process or material changes since the design basis was determined?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.8 Are all changes to systems with combustible dust controlled by a formal MOC system?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1NFPA 61 Annex F
What-if Analysis

• Brainstorming approach to identifying undesirable events

• Example:
  – What if Fan A shuts down?
  – How does the system respond?
  – What is the consequence?

• Can vary in scope and complexity

• Quality depends highly upon the level of knowledge of those involved in the process
## Example What-if Analysis – Dust Collector

<table>
<thead>
<tr>
<th>What-if</th>
<th>Consequence/ Hazard</th>
<th>Safeguards</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>The dust collector filters clog?</td>
<td>Buildup of dust in the process. Reduced velocity in the ductwork may result in buildup</td>
<td>Pressure sensor in dust collector interlocked with equipment</td>
<td>Consider implementing routine inspection and replacement of filters</td>
</tr>
<tr>
<td>The material in the dust collector self-heats?</td>
<td>Smoldering in the dust collector</td>
<td>Temperature sensor in dust collector</td>
<td>Consider adding a CO detector in collector</td>
</tr>
<tr>
<td>The material in the collector ignites?</td>
<td>Overpressure event in dust collector</td>
<td>Pressure relief vent installed, mechanical isolation installed</td>
<td>Consider adding a flameless vent to reduce thermal damage to nearby structures</td>
</tr>
</tbody>
</table>
Hazard and Operability Analysis (HAZOP)

• Systematic approach to identify hazard and operability problems resulting from deviations from the design intent

• Requires detailed knowledge of the system, including P&IDs, operation, and instrumentation

• Requires a trained leader, but must be performed by an interdisciplinary team.

• Process:
  – Identify specific points in process (nodes)
  – Uses “Guide Words” and “Parameters” to examine process deviations within each node

<table>
<thead>
<tr>
<th>Guide Words</th>
<th>Parameter</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>FLOW</td>
<td>NO FLOW</td>
</tr>
<tr>
<td>MORE</td>
<td>PRESSURE</td>
<td>HIGH PRESSURE</td>
</tr>
<tr>
<td>AS WELL AS</td>
<td>ONE PHASE</td>
<td>TWO PHASE</td>
</tr>
<tr>
<td>OTHER THAN</td>
<td>OPERATION</td>
<td>MAINTENANCE</td>
</tr>
</tbody>
</table>
Example HAZOP

**Process Section:** Bucket elevator  
**Design Intent:** Move material from lower conveyor to mixer  
**Guide Word:** No  
**Process Parameter:** Flow

**Deviation:** No Flow (No Bucket Movement)

**Consequences:**
1) Bucket elevator stops moving  
2) Material continues to be deposited into bucket elevator, results in excess material on floor

**Causes:**
1) Drivetrain bearing seizes  
2) Motor trips  
3) Drivetrain key breaks / belt breaks

**Safeguards:**
1) Routine maintenance of bucket elevator (bearing, motor, etc.)

**Actions:**
1) Consider adding alarm/shutdown if bucket elevator stops moving
Failure Modes and Effect Analysis (FMEA)

- Evaluates the ways *equipment* can fail and the effects these failures can have on a process
- An FMEA typically lists pieces of equipment with potential failure modes and the consequences of those failures

- Example valve failure modes
  - Flow control valve fails to close
  - Flow control valve fails to open
  - Flow control valve leaks

- For each failure mode, both the immediate effects of the failure and cascading effects should be considered

- FMEAs typically include safeguards and action steps
# Example FMEA – Bucket Elevator Bearing

<table>
<thead>
<tr>
<th>Item</th>
<th>Identification</th>
<th>Description</th>
<th>Failure Mode</th>
<th>Effects</th>
<th>Safeguards</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>Bucket Elevator Bearing</td>
<td>Bearing on shaft from motor to drive train</td>
<td>Seizes up</td>
<td>Bucket elevator stops moving</td>
<td>Preventative maintenance – routine greasing of bearing</td>
<td>Consider adding alarm/shutdown if bucket elevator stops moving</td>
</tr>
</tbody>
</table>
Assemble a Team

• Leader – Qualified Individual

• Qualifications to consider
  – Familiarity with standards
    – Member of Dust Committees (NFPA)
    – Member of ASTM Dust Testing Committees
  – Length of time in the field
  – Number of DHAs previously performed
  – Testing capabilities
  – Professional Engineer

• Members of the Owner/Operator – Diversity is key!
  – Operators, engineers, maintenance, supervisor, safety, etc.
Performing a DHA
Performing a DHA

1. Determine if a combustible dust is present
2. Determine which standards apply
3. Determine where a fire, flash fire, or explosion hazard exists
4. Prescriptive DHA Path:
   - Review current mitigation techniques and compare to requirements
4. Risk-based DHA:
   - Determine consequences and calculate risk
   - Determine if the calculated risk is acceptable
5. Make recommendations
6. Document the review
7. Implement recommendations
Determine if a combustible dust is present

• **5.1 Responsibility.**¹ The owner/operator of a facility with potentially combustible dusts shall be responsible for determining whether the materials are combustible or explosible, and, if so, for characterizing their properties as required to support the DHA.

• **5.2* Screening for Combustibility or Explosibility.**
  - **5.2.1** The determination of combustibility or explosibility shall be permitted to be based upon either of the following:
    (1) Historical facility data or published data that are deemed to be representative of current materials and process conditions
    (2) Analysis of representative samples in accordance with the requirements of 5.4.1 and 5.4.3

¹NFPA 652 §5.1
Trough Test – Combustibility Screening

- Flame held to one end of powder train
- Material “combustible” if flame propagates past heated zone
- In practice, only some samples that are “explosible” are also “combustible”
Go/No-Go Test – Explosibility Screening

• Explosion pressure measured in closed volume
• 2.5-kJ to 10-kJ chemical igniters typically used
• Material explosible if the pressure ratio (PR) is greater than 2

\[ PR = \frac{P_{ex} - \Delta P_{igniter}}{P_{ignition}} \]
Locations of Dust Accumulations and Clouds

Inside Equipment
- Inside process equipment
  - Silos, bins, screw conveyors, mixers, etc.
- Inside dust collection equipment
  - Ducts, collectors, and cyclones
- Conveyor belts and bucket elevators

Fugitive Dust
- Tables and other work surfaces
- Structural beams
- Floors
- Under floor grates
- Other horizontal surfaces
Determine which Standards Apply

• General Standards for Combustible Dust
  – NFPA 652 *Standard on Fundamentals of Combustible Dust*
  – NFPA 654 *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*

• Commodity Specific Standards
  – NFPA 61 *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
  – NFPA 120 *Standard for Fire Prevention and Control in Coal Mines*
  – NFPA 484 *Standard for Combustible Metals*
  – NFPA 655 *Standard for the Prevention of Sulfur Fires and Explosions*
  – NFPA 664 *Standard of Fires and Explosions in Wood Processing and Woodworking Facilities*
Determine which Standards and Guidelines Apply

- Related NFPA Standards and Practices
  - NFPA 68 Standard on Explosion Protection by Deflagration Venting
  - NFPA 69 Standard on Explosion Prevention Systems
  - NFPA 70 National Electric Code
  - NFPA 499 Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
  - NFPA 505 Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations
Determine which Standards and Guidelines Apply

• Other US Standards and Practices
  – FM Global Data Sheets
    – 7-17 Explosion Protection Systems
    – 7-73 Dust Collectors and Collection System
    – 7-76 Prevention And Mitigation Of Combustible Dust Explosions And Fire
  – Industry Specific Standards
  – Building and Fire Codes
Determine where a Fire, Flash Fire, or Explosion Hazard Exists

Combustible Dust (Fuel)

Oxidizer (Typically air)

Ignition Source

Dispersion

Confinement

Fire

Flash Fire

Explosion
Oxidizers

• Most processes operate in air (atmospheric oxygen)
• Some processes operate at reduced oxygen levels
• To determine if the oxygen level is low enough to prevent combustion, the LOC of the dust is required
Potential Ignition Sources

• Hot Surfaces
• High Temperatures
  – Combustion chambers or other burners
  – Ovens, melting equipment
• Arcs and Sparks
  – Static electricity
  – Mechanical sparking
  – Electrical sparks from motors
• Open Flames
• Self-heating / Smoldering
Competent Ignition Sources

• To determine if a potential ignition source is a competent ignition source, testing is required.

• Hot Surfaces:

• High Temperatures:

• Electrical arcs / Static:

• Self-heating / Smoldering:
  – UN Test N.4 – Test for Self-Heating Substances
Dispersion Mechanisms

• Inside Equipment
  – Fans and Blowers
  – Shaker tables

• Outside Equipment
  – Fans for creature comfort
  – Compressed air wands for cleaning
  – Vacuums
Dispersion Mechanisms

• A dust cloud is typically considered hazardous when the concentration exceeds 25% of the Minimum Explosible Concentration$^1$

NFPA 654 (2017) §A.3.3.10.2
Performing a DHA

1. Determine if a combustible dust is present
2. Determine which standards apply
3. Determine where a fire, flash fire, or explosion hazard exists
4. Prescriptive DHA Path:
   – Review current mitigation techniques and compare to requirements
4. Risk-based DHA:
   – Determine consequences and calculate risk
   – Determine if the calculated risk is acceptable
5. Make recommendations
6. Document the review
7. Implement recommendations
Mitigation Strategies
Eliminating Sides of the Pentagon

- Inerting
- Ignition Prevention
- Oxidizer
- Ignition Source
- Combustible Dust
- Housekeeping Dust Collection
- Inherently Safer Design
- Dispersion
- Confinement
- Explosion Venting
Alternate Protection Strategies

- Prescriptive Requirement
- Performance-Based Design
- Risk Evaluation
- Equivalent Design
- Prescriptive Requirement
- Prescriptive Requirement
- Prescriptive Requirement
Performance-Based Design

Design Objectives
- Life Safety
- Structural Integrity
- Mission Continuity
- Fire Spread and Explosion

Performance Criteria
- Prevent Ignition
- Limit Flame Propagation
- Minimize Enclosure Damage

Thresholds
- Surfaces < MIT
- Sparks < MIE
- Overpressures < $P_{es}$
Minimizing Dust Accumulations

- Dust accumulations can allow small events to become catastrophic
- Minimize escape of dust from equipment
  - Operate equipment at negative pressure
  - Maintain equipment seals
- Use dust collection systems in dust generation areas
- Frequent housekeeping to remove dust accumulations before they reach hazardous levels
- Do not neglect elevated surfaces or other difficult to reach areas
# Combustible Dust Accumulation Thresholds

<table>
<thead>
<tr>
<th>Standard</th>
<th>Combustible Dust Accumulation Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFPA 484 (Metal)</td>
<td>Color of underlying surfaces not discernible</td>
</tr>
<tr>
<td>NFPA 654 (General)</td>
<td>1/32” over 5% or 1000 ft²</td>
</tr>
<tr>
<td>NFPA 664 (Wood)</td>
<td>1/8”</td>
</tr>
<tr>
<td>NFPA 499 (Electrical Classification Class II</td>
<td>1/8”</td>
</tr>
<tr>
<td>Division 1)</td>
<td></td>
</tr>
<tr>
<td>NFPA 499 (Electrical Classification Class II</td>
<td>Color of underlying surfaces not discernible</td>
</tr>
<tr>
<td>Division 2)</td>
<td></td>
</tr>
</tbody>
</table>
Housekeeping

- Establish regular cleaning frequencies to maintain dust accumulations below hazard thresholds
  - Consider quantifying material cleaned
- Using cleaning methods that minimize generation of clouds
  - Vacuuming with vacuums approved for combustible dust and classified area
  - Gentle sweeping
- Vigorous sweeping, blow down or steam should only be used after:
  - Vacuuming
  - Elimination of ignition sources
Ignition Source Control

- Sparks (friction, electrical, static electricity)
  - Proper grounding, bonding
- Hot surfaces
- Hot work
- Open flames
- Heating systems
- Slipping belts
- Bearings
- Electrical Equipment (NFPA 499, 70)
- Minimize smoldering
Electrical Classification – NFPA 499

• Areas with combustible dust may be classified as Class II (dust) Division 1 or 2 by OSHA and NFPA 499 and 70
  – Classified electrical equipment should be used (NFPA 70 – NEC)
  – Classified industrial trucks (fork lifts) should be used (NFPA 505)

• Good housekeeping, prevention of dust releases, and partitions can reduce extent of classified areas
**Electrical Classification – NFPA 499 Chapter 6**

<table>
<thead>
<tr>
<th>Electrical Classification</th>
<th>Ignitable Dust Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class II, Division 1 or Zone 20/21</td>
<td>Dust clouds during normal conditions or &gt; 1/8” accumulation</td>
</tr>
<tr>
<td>Class II, Division 2 or Zone 22</td>
<td>Dust clouds during abnormal conditions or color of underlying surfaces not discernible</td>
</tr>
<tr>
<td>Unclassified</td>
<td>No visual dust clouds Color of underlying surfaces discernible</td>
</tr>
</tbody>
</table>

- The term *normal* does not necessarily mean the situation that prevails when everything is working properly.
- The term *abnormal* is used here in a limited sense and does not include a major catastrophe.
Explosion Protection of Equipment

- Explosion Venting
- Oxidant Concentration Reduction
- Dust Concentration Reduction
- Chemical Suppression
- Isolation
  - Active
  - Passive
- Pressure Containment

NFPA 68

NFPA 69
Report Findings
Report Findings

• Use format that works for facility
  – Tables of information from DHA
  – Slide decks with pictures of equipment and findings
  – Detailed prose report

• Typically iterative process
  – Initial report with follow-up items
  – Evaluation of mitigation options
  – Implementation plan
  – Final report detailing all protection present and recommendations
Example DHA
### Prescriptive Checklist DHA

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter Media Collector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constructed of non combustible material?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Is explosion protection present?</td>
<td>Yes</td>
<td>Determine Pmax/Kst and verify vent sizing</td>
</tr>
<tr>
<td>Are deflagration vents directed to safe area?</td>
<td>Unsure</td>
<td>Calculate fireball length and evaluate area</td>
</tr>
<tr>
<td>Is fire protection present?</td>
<td>No</td>
<td>Evaluate history of fires in similar collectors</td>
</tr>
<tr>
<td>Is ductwork free of manifolds?</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Is system bonded and grounded</td>
<td>Unsure</td>
<td>Determine MIE, obtain specs on flex connectors, audit bonding</td>
</tr>
<tr>
<td>Are manifolded systems isolated?</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Is upstream deflagration isolation present?</td>
<td>Unsure</td>
<td>Isolation flap only prevents propagation upstream to cyclone, consider bidirectional isolation</td>
</tr>
<tr>
<td>Is downstream deflagration isolation present?</td>
<td>Yes</td>
<td>Verify rotary valve complies with NFPA 69</td>
</tr>
<tr>
<td>Does exhaust air exit building</td>
<td>Yes</td>
<td>Evaluate nearby intakes</td>
</tr>
</tbody>
</table>

**Dust Collector System with Cyclone Separator**

![Diagram of Dust Collector System with Cyclone Separator](image)
## Risk Based DHA

**Dust Collector System with Cyclone Separator**

### Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter Media Collector</td>
<td>5</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

### Possible Ignition Sources

<table>
<thead>
<tr>
<th>Possible Ignition Sources</th>
<th>Prevention</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ember from upstream process</td>
<td>None</td>
<td>Evaluate frequency of embers and consider spark detection and extinguishing system</td>
</tr>
<tr>
<td>Static electricity</td>
<td>Conductive components, bonding and grounding</td>
<td>Determine MIE and evaluate need for static dissipative filter media.</td>
</tr>
<tr>
<td>Filter Break and Upstream Fan</td>
<td>None</td>
<td>Evaluate need for filter break detector and non sparking fan components</td>
</tr>
</tbody>
</table>

### Protection

<table>
<thead>
<tr>
<th>Protection</th>
<th>Vents ducted to outside building</th>
<th>Determine $P_{max}/K_{st}$, verify vent sizing and fireball area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflagration</td>
<td></td>
<td>Evaluate frequency of fire and need for fire suppression system</td>
</tr>
<tr>
<td>Fire</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Deflagration Isolation</td>
<td>Upstream flap, rotary valve</td>
<td>Consider bidirectional isolation between cyclone and filter media collector, evaluate rotary valve</td>
</tr>
<tr>
<td>Personnel</td>
<td>FR Clothing</td>
<td>Restrict access of personnel during operation</td>
</tr>
</tbody>
</table>
Additional References


Limitations

• The examples used in this presentation are meant to be illustrative. They should not be used as guidance for determining an adequate level of protection for a specific process or piece of equipment.
Best Practices for Performing a Combustible Dust Hazard Analysis

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