First Revision No. 138-NFPA 660-2026 [Global Input]

Annex C– Reserved [Move content from Annex C as B.5 and make Annex C a Reserved chapter]

B.5 Accumulated Fugitive Dust ~~(CMD-FUN)~~

~~***This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.***~~

~~C~~ B.5 .1 Accumulated Fugitive Dust.

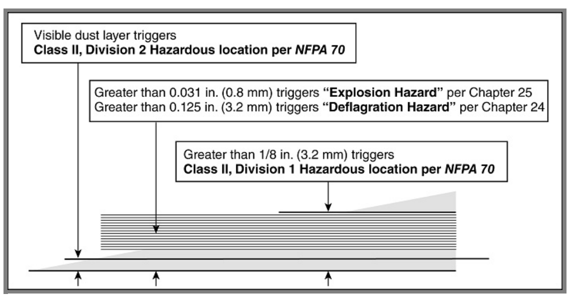
As noted elsewhere in the standard, there are two considerations for assessing accumulated fugitive dust hazards — one that indicates that a dust flash fire or dust explosion hazard exists and the other that indicates where protected electrical equipment might be needed. Figure C.1 is a representation of provisions defined in Articles 500–505 of *NFPA 70* to assist in determining where hazardous (classified) locations can exist.

Other factors associated with accumulated fugitive dust include the following:

(1) Accumulated fugitive dust is the single most important factor in propagating a deflagration within a building.

(2) Dust layers trigger critical hazard management decisions.

~~**Figure**~~ ~~**C**~~ **Figure** B . 5 **.** **1 Comparison of Accumulated Fugitive Dust Thicknesses. *(Source: J. M. Cholin Consultants, Inc.)***



~~C~~ **B** **.5** **.** 2 Electrical Equipment for Hazardous Occupancies.

All electrical equipment must be listed for use in the occupancy based on the class, division, and group classification. When all electrical equipment in the occupancy is listed for use in that occupancy, the electrical system is deemed to not be a likely igniter. The extent of the electrically classified area is controlled by the rate of dust release and the frequency of clean-up.

~~C~~ **B** **.5** **.** 3 Building Compartments.

Where management of the hazard is dependent on routine cleaning, that cleaning program should be outlined in the DHA.

~~C~~ B .5 . 4 Explosion Hazards.

Dust explosion hazards exist wherever combustible particulate solids are handled or produced. There is no alternative to proactively managing the hazard, and the following questions should be considered when assessing the risk:

(1) Is there accumulated fugitive dust? If so, how much is there and where is it?

(2) What is the MEC, MIE, and K_{St} of the particulate in the dust?

(3) Does the building compartment pose a deflagration hazard?

(4) Does the building compartment pose an explosion hazard?

(5) Does the building compartment pose a fire hazard?

Most instances of property damage and personnel injury are due to fugitive dust accumulations within building compartments. *Control, limitation, or elimination of accumulated fugitive dust are critical and the most important criteria for a safe workplace.*

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Fri Mar 27 12:05:02 EDT 2026

Committee Statement

Committee Statement: This material provides the criteria for evaluating the building compartment hazard and is more useful as part of Annex B.

Response Message: FR-138-NFPA 660-2026

First Revision No. 139-NFPA 660-2026 [Detail]

25.9.4.4.1.1 * Reserved.

25.9.6.5 ~~Reserved~~Hazardous (Classified) Locations for Electrical Installations.

25.9.6.5.1

~~The~~For a combustible dust operation, the ~~clean-air~~ clean-air plenum of an AMS shall be ~~considered~~ a ~~hazardous (classified)~~Class II, Division 2 or Zone 22 location.

25.9.6.5.2

For a hybrid mixture, the clean-air plenum shall additionally be a Class I, Division 2 or Zone 2 location.

~~**A.25.9.4.4.1.1**~~

~~**The committee recognizes the hazard of media failure and effect on electrical equipment. For a combustible dust, this would be a Class II, Division 2 or Zone 22 location. For a hybrid mixture, a Class I, Division 2 or Zone 2 would additionally be necessary.**~~

Supplemental Information

File Name	Description	Approved
660_Detail_FR-139_25.9.4.4.1.1.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Fri Mar 27 12:08:24 EDT 2026

Committee Statement

Committee Statement: The revision relocates the area classification designations to x.9.6 Ignition Source Control to align with the organization of the fundamental chapter. This revision also moves the area classification designations from annex to mandatory language to provide specific guidance.

Response Message: FR-139-NFPA 660-2026

Public Input No. 171-NFPA 660-2026 [Section No. 25.9.4.4.1.1]

First Revision No. 39-NFPA 660-2026 [Detail]

Delete this section and annex:

9.6.6.1.4.1*
This section shall not be required to be applied retroactively.
A.9.6.6.1.4.1
Flexible connectors wear out over time. The intent of this statement is that existing connectors would be replaced with compliant flexible connectors at the end of their service life.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 11:21:48 EST 2026

Committee Statement

Committee Statement: Note: this is being balloted separately from FR 38 which makes other revisions to 9.6.6. This revision is ONLY on the retroactivity statement 9.6.6.1.4.1 and its associated annex.

Flexible connectors are potential ignition sources with a limited lifecycle, and nonconforming flexible connectors can be replaced more readily than fixed equipment. Annex material to 9.6.1 provides guidance to the user on how to plan for timely retroactive replacements. Section 9.2 also provides the user with flexibility to assess the hazard of nonconforming connectors.

Response Message: FR-39-NFPA 660-2026

First Revision No. 41-NFPA 660-2026 [Detail]

In A.8.10.6 (which is moving to A.8.10.8):

The owner/operator should ~~consider~~ retain~~ing~~ the incident investigation reports for at least 5 years to be consistent with the DHA review schedule and in accordance with A. 8.13.1(3) .

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 12:13:04 EST 2026

Committee Statement

Committee Statement: This statement in the annex was inconsistent with the document retention requirements in 8.13.

Note: This change is being balloted separately from the rest of the revisions to 8.10 and the associated annexes, which are done by First Revision 40.

Response Message: FR-41-NFPA 660-2026

First Revision No. 48-NFPA 660-2026 [Section No. 2.3]

2.3 Other Publications.

2.3.1 AMCA International Publications.

Air Movement and Control Association International, Inc., 30 West University Drive, Arlington Heights, IL 60004-1893.

AMCA Standard 99, *Standards Handbook*, ~~2016~~ 2015 . (Supersedes AMCA Standard 99-0401.)

2.3.2 ASME Publications.

American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

ANSI/ASME B31.1, *Power Piping*, ~~2022~~ 2024 .

ASME B31.3, *Process Piping*, ~~2022~~ 2024 .

Boiler and Pressure Vessel Code, ~~2023~~ 2025 .

2.3.3 ASTM Publications.

ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D378, *Standard Test Methods for Rubber (Elastomeric) Conveyor Belting, Flat Type*, 2010, reapproved 2016.

ASTM E11, *Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves*, ~~2022~~ 2024 .

ASTM E136, *Standard Test Method for Assessing Combustibility of Materials Using a Vertical Tube Furnace at 750°C*, ~~2022~~ 2026 .

ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, 2019, reapproved 2025 .

ASTM E1515, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*, 2014, reapproved 2022.

ASTM E2019, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*, 2003, reapproved ~~2019~~ 2025 .

ASTM F1002, *Standard Performance Specification for Protective Clothing and Materials for Use by Workers Exposed to Specific Molten Substances and Related Thermal Hazards*, 2015, reapproved 2021.

~~ISO/ASTM 52900, *Additive Manufacturing — General Principles — Fundamentals and Vocabulary* , 2021.~~

2.3.4 BSI Publications.

BSI British Standards, 12950 Worldgate Drive, Suite 800, Herndon, VA 20170.

BS EN 17348, *Requirements for design and testing of vacuum cleaners for use in potentially explosive atmospheres*, 2022.

2.3.5 IEC Publications.

International Electrotechnical Commission, 3 rue de Varembé, P.O. Box 131, CH-1211 Geneva 20, Switzerland.

IEC 61340-4-4, *Electrostatics — Part 4-4: Standard Test Methods for Specific Applications — Electrostatic Classification of Flexible Intermediate Bulk Containers (FIBC)*, 2018.

2.3.6 ISA Publications.

International Society of Automation, 67 T. W. Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709.

ISA 84.00.01, *Functional Safety*: *Safety Instrumented Systems for the Process Industry Sector*, 2004.

2.3.7 MSHA Publications.

Mine Safety and Health Administration (MSHA), 201 12th Street South, Suite 401, Arlington VA 22202-5450.

MSHA Title 30, Code of Federal Regulations, Part 18, Section 12.18.6.5 and Section 18.65, "2G Test."

2.3.8 UL Publications.

Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 4040, *Outline of Investigation for Portable Wet-Type Dust Collectors for Collection of Combustible Metals*, 2016.

~~UL/CSA 60335-2-69, *Household and similar electrical appliances — Safety — Part 2-69: Particular requirements for wet and dry vacuum cleaners, including power brush for commercial use* , 2022.~~

2.3.9 UN Publications.

United Nations Publications Customer Service, P.O. Box 960, Herndon, VA 20172.

Recommendations on the Transport of Dangerous Goods: Model Regulations — Manual of Tests and Criteria, 2019.

2.3.10 US Government Publications.

US Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Title 29, Code of Federal Regulations, Part 1910.242(b), "Hand and Portable Powered Tools and Equipment, General."

2.3.11 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2020.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 15:30:06 EST 2026

Committee Statement

Committee Statement: Updating references to the most recent editions.

Response Message: FR-48-NFPA 660-2026

Public Input No. 174-NFPA 660-2026 [Section No. 2.3.3]

First Revision No. 50-NFPA 660-2026 [Section No. 2.4]

2.4 References for Extracts in Mandatory Sections.

NFPA 30, *Flammable and Combustible Liquids Code,* 2024 edition.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* 2023 edition.

NFPA 69, *Standard on Explosion Prevention Systems,* 2024 edition.

NFPA 70®, *National Electrical Code®*, ~~2023~~ 2026 edition.

NFPA 77, *Recommended Practice on Electricity,* 2024 edition.

NFPA 221, *Standard for High Challenge Fire Walls, Fire Walls, and Fire Barrier Walls,* 2024 edition.

NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* 2024 edition.

NFPA 921, *Guide for Fire and Explosion Investigations,* 2024 edition.

NFPA 1250, *Recommended Practice in Fire and Emergency Service Organization Risk Management,* ~~2020~~ 2026 edition.

~~NFPA 1451, *Standard for a Fire and Emergency Service Vehicle Operations Training Program,* 2018 edition.~~

NFPA 1400, *Standard on Fire Service Training,* 2027 edition.

NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* 2023 edition.

NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* 2025 edition.

Supplemental Information

File Name	Description	Approved
660_FR-50_2.4.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 15:34:36 EST 2026

Committee Statement

Committee Statement: This revision updates extracted text in accordance with the Extract Policy.

Response Message: FR-50-NFPA 660-2026

First Revision No. 45-NFPA 660-2026 [Section No. 3.3.2]

3.3.2* Additive Manufacturing (AM).

The process of joining ~~materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies. [~~ ~~**ISO/ASTM 52900,**~~ ~~2021]~~ powders, filaments, and other solid and liquid materials to build three-dimensional objects layer-by-layer from digital models. (CMD-FUN)

A.3.3.2 Additive Manufacturing (AM).

Additive manufacturing, commonly referred to as AM, adds material layer by layer to form complex geometries unlike milling, drilling, and other traditional subtractive methods that cut material away. Although AM is sometimes referred to as 3D printing~~; however~~ , this is only one part of the process that includes powder storage and transfer, sieving and recycling powders, depowdering printed parts, and post-processing . (CMD-FUN)

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 14:43:04 EST 2026

Committee Statement

Committee Statement: Revising the definition to be unique to NFPA 660 and better serve the users of this standard, and to include other materials beyond powder.

Response Message: FR-45-NFPA 660-2026

First Revision No. 14-NFPA 660-2026 [Section No. 4.2.3]

4.2.3* Mitigation of ~~Fire Spread~~ Fires, Flash Fires , Explosions, or Releases of Hazardous Materials.

The facility and processes shall be designed to prevent fires, flash fires, explosions, or releases of hazardous materials that can cause failure of adjacent compartments, emergency life safety systems, adjacent properties, adjacent storage, or the facility's structural elements.

4.2.3.1

The structure shall be designed, constructed, and maintained to prevent fire or explosions from causing failure of load-bearing structural members, propagating into adjacent interior compartments, and incapacitating fire-protective and emergency life safety systems in adjacent compartments.

4.2.3.2

The structure shall be located, designed, constructed, equipped, and maintained to prevent the propagation of fire or explosion to or from adjacent storage or structures.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 15:16:58 EST 2026

Committee Statement

Committee Statement: Flash fires were added because they are an important hazard to be considered by this standard and to maintain consistency with 6.3.4.

Response Message: FR-14-NFPA 660-2026

First Revision No. 8-NFPA 660-2026 [Section No. 4.2.4]

4.2.4 Compliance Options.

~~The objectives in Section 4.2 shall be deemed to have been met by implementing both of the following:~~

~~The prescriptive requirements in Chapters 5 , 7 , and 8~~

~~A hazard management program in conformance with the prescriptive requirements of Chapter 9 and the prescriptive hazard management requirements of the relevant industry- or commodity-specific chapter, or that meets the objectives of Chapter 4 and the relevant industry- or commodity-specific chapter through a performance-based design in accordance with Chapter 6~~

4.2.4.1

The objectives in Section 4.2 shall be deemed to have been met by implementing both of the following:

(1) The prescriptive requirements in Chapters 5, 7, and 8

(2) A hazard management program in conformance with the prescriptive requirements of Chapter 9 and the prescriptive hazard management requirements of the relevant industry- or commodity-specific chapter~~, or that meets the objectives of Chapter 4 and the relevant industry- or commodity-specific chapter through a performance-based design in accordance with Chapter 6~~

4.2.4.2*

A performance-based design in accordance with Chapter 6 shall be permitted as an alternate means of satisfying 4.2.4.1(2) .

A.4.2.4.2

Usually, a facility or process system is designed using the prescriptive criteria until a prescribed solution is found to be infeasible or impracticable. Then the designer can use the performance-based option to develop a design, addressing the full range of fire, flash fire, and explosion scenarios and the impact on other prescribed design features. Consequently, facilities are usually designed not by using performance-based design methods for all facets of the facility but rather by using a mixture of both design approaches as needed. Refer to Chapters 21, 22, 23, 24, and 25 for the prescriptive hazard management requirements in the relevant industry- or commodity-specific chapters.

Supplemental Information

File Name	Description	Approved
660_FR_8_4.2.4.docx		
660_FR_8_4.2.4.docx	For prod use	

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 11:34:54 EST 2026

Committee Statement

Committee Statement: The original wording was confusing. The revised text more clearly limits the performance-based option to the mandatory requirements in the second list item (Chapter 9).

Response Message: FR-8-NFPA 660-2026

First Revision No. 9-NFPA 660-2026 [Section No. 5.2.2]

5.2.2*

The determination of combustibility or explosibility shall be permitted to be based upon historical facility test data or published test data that are deemed to be representative of current materials and process conditions.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 12:37:31 EST 2026

Committee Statement

Committee Statement: The addition of "test" aligns with the annex and clarifies that the absence of previous incidents cannot be used as the basis for lack of a hazard, as described in the annex of this section and in 5.2.4.

Response Message: FR-9-NFPA 660-2026

First Revision No. 10-NFPA 660-2026 [Section No. 5.3]

5.4* Self-Heating ~~and~~ , Reactivity, and Other Hazards Associated with Combustible Dusts .

Where self-heating, thermal instability, water reactivity, or chemical reactivity hazards exist, the process, storage, and transport conditions shall be controlled to prevent a fire, explosion, or toxic exposure.

A.5.4

Some materials have multiple potential physical hazards such as combustibility, explosibility, reactivity, and propensity to self-heat. Annex J of NFPA 400 contains a comparison of different definitions used by different standards, codes, and regulations for hazardous materials. Reactivity hazards can release energy and produce products that are more readily ignitible than the original material, thus creating or exacerbating a combustion hazard that would be within the scope of a DHA. Reactivity of combustible particulates by means other than self-heating could occur due to thermal instability or contact with an incompatible material. The ensuing chemical reaction could generate heat and gases, and the gases generated could be toxic, corrosive, or flammable.

Identification of potential incompatibility with water should be a high priority because humidity in the air might be sufficient to initiate reactions with materials that are incompatible with water. The need to know whether to avoid material contact with water is important, since water is often present at the site for process use, cleaning, utility use, or emergency response. Water is often the first choice as a fire extinguishing agent, so knowing whether to use or avoid water when extinguishing fires is critical.

Users should consult safety data sheets (SDS) for specific information and guidance on safe handling, personal protective equipment (PPE), and storage and transportation of chemicals.

5.4.1 Self-Heating Hazard Evaluations.

5.4.1.1

A documented self-heating hazard evaluation shall be performed where one or more of the following conditions is present:

(1) Bulk storage or transport of combustible particulate solids in quantities of 1000 kg (2203 lb) or larger

(2) More than 10 kg (22 lb) of material is present in dryer discharge bins and hoppers at elevated temperatures

(3) A potential self-heating scenario has been identified in the DHA

5.4.1.2

The self-heating hazard evaluation method shall be according to 5.4.1.2.1 or according to 5.4.1.2.2 and 5.4.1.2.3.

5.4.1.2.1

A documented review shall be conducted of experience storing and transporting the bulk material in quantities comparable to or larger than those used in the facility, at temperatures comparable to or higher than the expected storage or transport temperatures, and for durations comparable to or longer than the expected storage or transport duration.

5.4.1.2.2*

~~Laboratory~~ Where required, laboratory tests shall be conducted to determine self-heating potential and rate.

5.4.1.2.3*

A theoretically based scaling analysis shall be conducted using the laboratory test data to determine the critical temperatures for self-heating at the scale being used at the facility.

5.4.2 Thermal Instability Hazard Evaluations.

5.4.2.1

A thermal instability hazard evaluation shall be conducted when one or more of the following conditions exist:

(1) More than 1000 kg (2200 lb) of combustible particulate are stored for longer than 8 hours in a bin or hopper or bulk pile at a temperature higher than 30°C (104°F).

(2) More than 100 kg (220 lb) of particulate product are in an oven or dryer for more than 1 hour.

(3) A scenario where heated material can reside for extended periods of time in process equipment has been identified in the DHA.

5.4.2.2

The thermal instability hazard evaluation method shall be according to either 5.4.2.2.1 or 5.4.2.2.2.

5.4.2.2.1

A documented review of pertinent reactivity literature, safety data sheets, and operating experience shall be conducted, identifying the reactivity of the material, thermal decomposition onset temperature, and, where possible, the reaction byproducts including gases that could be toxic, corrosive, or flammable.

5.4.2.2.2*

~~Temperature~~ Where required, temperature sensitivity testing shall be conducted at temperatures that would correspond to the highest possible temperature the material could attain based on exposure conditions determined from the DHA.

5.4.3 Water Reactivity Hazard Evaluations.

5.4.3.1

A water reactivity hazard evaluation shall be conducted when one or both of the following conditions exist:

(1) A water-based fire suppression system is used for the combustible particulate material.

(2) Particulate product or dust is exposed to process water, condensed water vapor, or outdoor precipitation.

5.4.3.2

The water reactivity hazard evaluation method shall be according to either 5.4.3.2.1 or 5.4.3.2.2.

5.4.3.2.1*

A documented review of pertinent reactivity literature, reactivity screening software, and operating experience shall be conducted, identifying the reactivity of the material and, where possible, the reaction byproducts including gases that could be toxic, corrosive, or flammable.

5.4.3.2.2

~~Water~~ Where required, water reactivity testing shall be conducted using the UN *Recommendations on the Transport of Dangerous Goods, Model Regulations — Manual of Tests and Criteria* water reactivity Test N.5 for potential Division 4.3 water-reactive materials that emit flammable gases, or another test acceptable to the AHJ.

5.4.4 Chemical Reactivity Hazard Evaluations.

5.4.4.1

A chemical reactivity hazard evaluation shall be conducted when particulate product or dust could be exposed to an incompatible material or a reactivity scenario has been otherwise identified in the DHA.

5.4.4.2

The chemical reactivity hazard evaluation method shall be according to either 5.4.4.2.1 or 5.4.4.2.2.

5.4.4.2.1

A documented review of pertinent reactivity literature, reactivity screening software, and operating experience shall be conducted, identifying the reactivity of the material and, where possible, the reaction byproducts including gases that could be toxic, corrosive, or flammable. *(See A.5.4.3.2.1.)*

5.4.4.2.2*

~~Calorimetry~~ Where required, calorimetry testing shall be used for determining potential chemical reactivity hazards.

Supplemental Information

File Name	Description	Approved
660_FR_10_5.4.docx		
660_FR_10_5.3.docx	For prod use	

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 13:30:10 EST 2026

Committee Statement

Committee Statement: The title of this section is being revised to cover all of the hazards described within.

The section on "other hazards" is being moved after "Combustibility and Explosibility Tests" so to not split up the requirements that relate to combustibility and explosibility of combustible dusts. Sampling applies to all of the hazards described.

"Where required" has been added to the sections about testing, to clarify that testing may not be required based on the documented reviews in 5.4.1.2.1, 5.4.2.2.1, 5.4.3.2.1, and 5.4.4.2.1.

Text has been added to the annex to reference Annex J of NFPA 400, because there are many different definitions used for hazardous materials and Annex J of NFPA 400 serves as a useful summary for users of NFPA 660.

Response Message: FR-10-NFPA 660-2026

Public Input No. 177-NFPA 660-2026 [Section No. A.5.3]

First Revision No. 12-NFPA 660-2026 [Section No. 5.4.3.1]

5.3.3.1

Where the explosibility is not known, determination of explosibility of dusts shall be determined according to one of the following tests:

(1) The “Go/No-Go” screening test methodology described in ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, using a 5 kJ ignition source in a 20 L (5.3 gal) sphere, or a 10 kJ ignition source in a 1 m^3 (35.3 ft^3) sphere

~~ASTM E1515, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*~~

(2) An equivalent test methodology

Supplemental Information

File Name	Description	Approved
660_FR-12_5.4.3.1.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 14:34:24 EST 2026

Committee Statement

Committee Statement: NFPA 660 previously allowed for use of either the go/no go screening test methodology described in ASTM E 1226, "Standard Test Method for Explosibility of Dust Clouds" or ASTM E 1515, “Standard Test Method for Minimum Explosible Concentration of Combustible Dusts” to determine if the dust/powder is explosible (Section 5.4.3).

ASTM E 1515 (Section 5.5) recommends use of either 2500 or 5000 J pyrotechnic ignitors ignition sources for measuring the MEC of dusts in 20-L chambers.

ASTM E 1226, as currently written (Section 5.4), allows for use of either a 5.0 kJ or 10.0 kJ igniters to conduct testing to evaluate deflagration parameters of dusts. Also in Section 13, Explosibility Screening test, Section 13.1.1 states, “conduct initial tests using a 5 kJ or greater ignition source”.

Based on the choice of test method and the variability of ignition sources allowed, it is possible to determine explosibility properties, based on igniter energy levels that could vary by a magnitude of four (4). This can lead to reporting conflicting results. For example, results of the MEC test may indicate that the sample has no MEC, suggesting the sample is nonexplosible, while Screening test results may be reported as “Go”, indicating that the dust is explosible.

The potential ramifications of this present a significant process safety issue.

ASTM E1515 has been deleted because it can be considered an equivalent test method when performed with a 5 kJ igniter.

Response Message: FR-12-NFPA 660-2026

Public Input No. 5-NFPA 660-2025 [Section No. 5.4.3.1]

First Revision No. 13-NFPA 660-2026 [Section No. 6.3.4]

6.3.4 Mitigation of ~~Fire Spread~~ Fires, Flash Fires , Explosions, or Releases of Hazardous Materials.

~~When limitation~~ Where mitigation of fires , flash ~~fire, and explosion spread~~ fires, explosions, or releases of hazardous materials is to be achieved, all of the following criteria shall be demonstrated:

(1) Adjacent combustibles shall not attain their ignition temperature.

(2) Building design and housekeeping shall prevent combustibles from accumulating exterior to the enclosed process system to a concentration that is capable of supporting propagation.

(3) Particulate processing systems shall prevent fire, flash fire, or explosion from propagating from one process system to an adjacent process system or to the building interior.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 15:06:04 EST 2026

Committee Statement

Committee Statement: Aligning the text in this section with the title, and with section 4.2.3. Flash fires are referenced in list item (3) and should be referenced in the title and introductory statement.

Response Message: FR-13-NFPA 660-2026

Public Input No. 170-NFPA 660-2026 [Section No. 6.3.4]

First Revision No. 43-NFPA 660-2026 [Section No. 7.1.4]

7.1.4*

The DHA shall be reviewed and updated at least every 5 years.

A.7.1.4

The approach to updating the DHA can vary depending upon particular circumstances. The quality of the previous DHA should be evaluated. If the quality of the DHA or the qualifications of the prior team are deemed inadequate, the update might require performing a completely new DHA. On the other hand, if the qualifications of the prior team and the quality of the DHA are deemed acceptable, the update could involve a review of the management of change reviews processed and the incident investigation reports generated since the prior DHA with only selected portions of the prior report updated with this new information. If substantive changes have been made to the process, or if significant incidents have occurred, the degree of review, frequency of updates, and modification of the prior report could be greater. The owner/operator should consider such factors when determining the nature, frequency, and scope of the DHA update.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 13:44:26 EST 2026

Committee Statement

Committee Statement: This new annex material provides additional guidance about what is expected when the DHA is reviewed and updated.

Response Message: FR-43-NFPA 660-2026

First Revision No. 42-NFPA 660-2026 [Section No. 7.2.2]

7.2.2* Qualifications.

The DHA and subsequent 5-year reviews shall be performed or led by a qualified person who possesses documented experience and education regarding methods for performing a DHA and the assessment and identification of mitigation or elimination options for the fire, flash fire, explosion, and related hazards of the specific type or types of combustible dusts involved in the facility.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 13:40:00 EST 2026

Committee Statement

Committee Statement: There have been questions as to whether the DHA update required by 7.1.4 needed to be done by a qualified person. This revision clarifies that the same requirements apply.

Response Message: FR-42-NFPA 660-2026

First Revision No. 15-NFPA 660-2026 [Section No. 7.3.3.3]

See FR-16

7.3.3.3

Each part of the process that could potentially contain all of the following conditions shall be both considered a dust flash fire ~~or explosion~~ hazard and ~~shall be~~ documented as such:

(1) A combustible particulate solid of sufficiently small particle size and sufficient quantity

(2) Air or other oxidizing atmosphere

(3) A competent ignition source

(4) A credible suspension mechanism

7.3.3.4

Each part of the process that could potentially contain all of the following conditions shall be both considered an explosion hazard and documented as such:

(1) A combustible particulate solid of sufficiently small particle size and sufficient quantity

(2) Air or other oxidizing atmosphere

(3) A competent ignition source

(4) A credible suspension mechanism

(5) Confinement sufficient to accumulate pressure

Supplemental Information

File Name	Description	Approved
660_FR_15_7.3.3.3_and_7.3.3.4.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 15:59:46 EST 2026

Committee Statement

Committee Statement: This text was added for clarity to describe the 5 elements needed for a dust explosion as per the dust explosion pentagon.

Response Message: FR-15-NFPA 660-2026

Public Input No. 81-NFPA 660-2025 [New Section after 7.3.3.3]

First Revision No. 47-NFPA 660-2026 [Section No. 7.3.4.2.2]

7.3.4.2.2

The threshold housekeeping dust accumulation limit and nonroutine dust accumulation levels (e.g., from a process upset) shall be in accordance with relevant industry- or commodity-specific requirements identified in Chapters 21 through ~~24~~ 25 .

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 15:01:37 EST 2026

Committee Statement

Committee Statement: The thresholds in all of the industry- and commodity-specific chapters were intended to be included here.

Response Message: FR-47-NFPA 660-2026

First Revision No. 17-NFPA 660-2026 [Section No. 7.3.4.3]

7.3.4.3

Each building or building compartment that could potentially contain all of the following conditions shall be both considered a dust flash fire ~~or explosion~~ hazard and ~~shall be~~ documented as such:

(1) A combustible particulate solid of sufficiently small particle size and sufficient quantity

(2) Air or other oxidizing atmosphere

(3) A competent ignition source

(4) A credible suspension mechanism

7.3.4.4

Each building or building compartment that could potentially contain all of the following conditions shall be both considered an explosion hazard and documented as such:

(1) A combustible particulate solid of sufficiently small particle size and sufficient quantity

(2) Air or other oxidizing atmosphere

(3) A competent ignition source

(4) A credible suspension mechanism

(5) Confinement sufficient to accumulate pressure

Supplemental Information

File Name	Description	Approved
660_FR_17_7.3.4.3_and_7.3.4.4.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Jan 26 16:36:15 EST 2026

Committee Statement

Committee Statement: 7.3.4.4 was added for clarity to describe the 5 elements needed for a dust explosion as per the dust explosion pentagon.

"sufficient quantity" of a combustible particulate solid is necessary for completeness.

In response to PI 78, the proposed modification to list item (4) is now addressed by list item (1) which requires a sufficient quantity of the combustible particulate solid.

Response Message: FR-17-NFPA 660-2026

Public Input No. 78-NFPA 660-2025 [Section No. 7.3.4.3]

Public Input No. 79-NFPA 660-2025 [New Section after 7.3.4.3]

First Revision No. 19-NFPA 660-2026 [Section No. 8.4.2.2.2]

8.4.2.2.2 Centralized Vacuum Cleaning Systems.

A centralized vacuum cleaning system ~~remotely installed beyond the hazardous (classified) location~~ , in conformance with Section 9.4and 9.6.5 , shall be permitted to be used for vacuuming in combustible dust hazardous (classified) locations and where flammable vapors or gases are present in combustible dust hazardous (classified) locations.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 09:07:35 EST 2026

Committee Statement

Committee Statement: Centralized vacuum cleaning systems are commonly installed in Class II, Group G, Div 2 classified areas in grain elevators, feed mills, and flour mills. This is acceptable when they are properly protected, similar to a dust collector installed in the same area classification. Section 9.6.5 contains requirements for electrical installations in hazardous (classified) locations.

Response Message: FR-19-NFPA 660-2026

Public Input No. 68-NFPA 660-2025 [Section No. 8.4.2.2.2]

First Revision No. 20-NFPA 660-2026 [Section No. 8.7.2]

8.7.2*

The inspection, testing, and maintenance program shall include the following:

(1) Fire and explosion protection and prevention equipment ~~in accordance with the applicable NFPA standards~~

(2) Dust control equipment

(3) Housekeeping equipment

(4)* Potential ignition sources and their detection and control measures

(5) Electrical, process, and mechanical equipment

(6)* Instrumentation, including process interlocks

(7) ~~Lubrication of bearings~~ Bearings and other equipment requiring lubrication

(8)* Tramp metal detection and removal devices

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 09:40:40 EST 2026

Committee Statement

Committee Statement: The statement "in accordance with the applicable NFPA standards" is covered already in 8.7.1 and does not need to be repeated here. The original wording would potentially limit the standards to only NFPA standards, which was not the intent.

List item (4) is amended to clarify that what should be maintained is the devices installed to detect the applicable causes.

List item (7) is amended to clarify the item to be inspected rather than the method of correction.

Response Message: FR-20-NFPA 660-2026

First Revision No. 21-NFPA 660-2026 [Section No. 8.8.3]

8.8.3

Refresher training shall be provided ~~at least every three years after initial training or as required by the applicable industry- or commodity-specific chapters of this standard, whichever is shorter~~ annually .

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 10:07:58 EST 2026

Committee Statement

Committee Statement: This section is being revised to align with some of the industry- and commodity-specific chapters and requirements for contractor training. Refresher training does not have to be as comprehensive as the original training.

Response Message: FR-21-NFPA 660-2026

Public Input No. 87-NFPA 660-2025 [Section No. 8.8.3]

First Revision No. 22-NFPA 660-2026 [Section No. 8.9.3.6]

8.9.3.6

Contractors shall receive refresher training in accordance with 8.9.3 annually.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 10:23:01 EST 2026

Committee Statement

Committee Statement: This revision ensures that the other requirements in 8.9.3 are covered by the refresher training.

Response Message: FR-22-NFPA 660-2026

Public Input No. 26-NFPA 660-2025 [Section No. 8.9.3.6]

First Revision No. 40-NFPA 660-2026 [Section No. 8.10]

8.10* Incident Investigation.

A.8.10

The retroactivity of Chapter 8 is not intended to require investigation of incidents that occurred prior to the adoption of this standard.

~~To thoroughly assess the risks, analyze the incident, and take any corrective steps necessary, investigations should be conducted promptly based on the nature of the incident and in coordination with the AHJ (as applicable).~~

~~The investigation should include root cause analysis and should include a review of existing control measures and underlying systemic factors. Appropriate corrective action should be taken to prevent recurrence and to assess and monitor the effectiveness of actions taken.~~

~~Such investigations should be carried out by trained persons (internal or external) and include participation of workers. All investigations should conclude with a report on the action taken to prevent recurrence.~~

~~Investigation reports should be reviewed with all affected personnel and their representatives (including contract employees where applicable) whose job tasks are relevant to the incident findings, and with the health and safety committee, to make any appropriate recommendations. Any recommendations from the safety and health committee should be communicated to the appropriate persons for corrective action, included in the management review, and considered for continual improvement activities.~~

~~A system should be established to promptly address and resolve the incident report findings and recommendations.~~

~~Corrective actions resulting from investigations should be implemented in all areas where there is a risk of similar incidents and subsequently checked to avoid repetition of injuries and incidents that gave rise to the investigation.~~

~~Reports produced by external investigation agencies should be acted upon in the same manner as internal investigations.~~

~~Incident investigation reports should be made available to affected employees and their representatives at no cost.~~

~~See the CCPS *Guidelines for Investigating Process Safety Incidents* for additional guidance on incident investigation.~~

8.10.1*

The owner/operator shall have a system to ensure that incidents that result in a fire, flash fire, or explosion are reported and investigated.

A.8.10.1

To thoroughly assess the risks, analyze the incident, and take any corrective steps necessary, investigations should be conducted promptly based on the nature of the incident and in coordination with other agencies (as applicable). In some cases, such as those involving injury to personnel or response from public emergency responders, the applicable agencies can include Bureau of Alcohol, Tobacco, and Firearms; US Chemical Safety Board; FBI; OSHA; state police; state fire marshal; local code enforcement authorities; property/casualty insurers; and workers' compensation insurers as a matter of law or legal contract.

Incidents can be actual loss events or near misses as described in A.8.10.2 . The severity and complexity of incidents can vary significantly. Even small incidents and near misses should be investigated to identify learnings that, if properly applied, could prevent more significant events in the future. Accordingly, the incident investigation system should be flexible to address incidents that can range from minor to catastrophic, rather than being a one-size-fits-all system.

The investigation should identify the underlying systemic factors that caused the incident (i.e., the root causes) and other contributing factors. It should also include a review of success or failure of existing control measures to function as intended.

Guidance for the conduct of incident investigations is provided in NFPA 921 and Center for Chemical Process Safety's (CCPS) *Guidelines for Investigating Process Safety Incidents* .

8.10.2*

Events that could have resulted in fires, flash fires, or explosions under different circumstances but where property losses or injuries were not experienced shall be investigated.

A.8.10.2

In addition to investigation of fires, flash fires, and explosions, it is also a good practice to investigate near misses (events that could have resulted in fires, flash fires, or explosions under different circumstances) and all activations of active fire and explosion mitigation systems. It is important to educate facility personnel on the concept of what a near miss is and to clearly communicate their responsibility for reporting both incidents and near misses. Near-miss events often indicate an underlying problem that should be corrected.

~~Near-miss events often indicate an underlying problem that should be corrected.~~ Barriers to reporting should be removed, as described in ANSI/~~AIHA~~ ASSP Z10, *Occupational Health and Safety Management Systems*. ~~Investigations should include workers and their representatives, as appropriate.~~

8.10.3*

Once any emergency response activities have been completed and, if applicable, the ~~scene~~ facility has been released by the AHJs back to the owner/operator, ~~incident investigations shall be promptly initiated by management personnel or by a designee who has a working knowledge of the facility and processes~~ the owner/operator shall initiate the necessary steps to secure the incident scene and to preserve and collect evidence .

A.8.10.3

It is critical to secure the scene to preserve evidence that is necessary in making accurate determinations of cause and origin of the incident and the event sequence that led to the incident. Prior to any on-scene activity, the site should be evaluated by a qualified structural engineer for structural stability to ensure the safety of investigators prior to starting the on-scene investigatory work.

Unauthorized personnel should be prohibited from entering the area by the use of barriers, signage, hazards tape, posted security personnel, or other methods deemed to be effective. The scene should remain secured until all scene documentation and evidence preservation is completed.

Clean-up of the scene or removal of equipment or debris from the area should be prohibited prior to the investigation.

Emergency response personnel should be interviewed to determine which, if any, of their actions could have had an impact on the evidence (e.g., changing valve positions, removal of debris, removal or relocation of equipment, and so on).

Evidence collection and preservation activities could include the following:

(1) Mapping the positions of key items of debris.

(2) Documenting the scene and equipment by taking still photos and videos of the area.

(3) Requesting that witnesses to the event provide written statements of what they observed before they leave the facility. These witnesses should be interviewed in detail at a later date.

(4) Securing documentary evidence (e.g., procedures, logsheets, instrument charts, and so on) and electronic records (e.g., distributed control system data, and so on).

8.10.4*

Management shall designate a qualified person who has a working knowledge of the facility and processes to assemble an investigation team and initiate the incident investigation.

A.8.10.4

The person initiating the investigation should identify the principal investigation team members. This person might or might not be the investigation team lead, but will have responsibility for overseeing the investigation process.

It is important to ensure the objectivity of those persons responsible for the investigation. For more significant events (e.g., incidents involving fatalities) it might be appropriate for the team leader to come from outside the site. Personnel directly affiliated with the subject event can serve as witnesses in the investigation but should not be part of the investigation team.

The team leader should be trained and experienced in conducting incident investigations. For example, Chapter 4 of NFPA 1033 specifies qualifications that might be appropriate for more significant events but might not be necessary for less significant incidents and near misses.

Investigations should include participation of workers and their representatives, as appropriate.

All members of the investigation team should have a general understanding of combustible dust hazards. Collectively, the team should have knowledge of the following:

(1) The equipment, systems, processes, and materials involved in the incident

(2) The failure modes of the involved equipment and systems

(3) Maintenance practices and schedules

(4) The specific hazards presented by each piece of equipment involved in the incident

(5) The specific hazards associated with the materials involved in the incident (e.g., combustibility, self-heating, reactivity, and so on)

Other personnel with more-specialized technical expertise can be involved in the investigation on an as-needed, rather than full-time, basis.

Some investigations of simpler, lower consequence events might be investigated by as few as one or two persons. Even in these situations, the person leading the investigation should have a familiarity with basic incident investigation principles and techniques.

The use of certified investigators might be warranted for more significant events. Such certifications include the National Association of Fire Investigators' (NAFI) Certified Fire and Explosion Investigators (CFEI) and the International Association of Arson Investigators' Certified Fire Investigator (IAAI-CFI).

8.10.5*

The investigation team shall analyze the evidence, identify the initiating and contributing factors leading to the event, including root causes, and propose recommendations intended to prevent reoccurrence of the event.

A.8.10.5

The goal of the investigation is to identify the factors (e.g., human errors, equipment or system failures, external factors, and so on) that initiated and contributed to the sequence of events leading up to incident or near miss.

This often involves constructing a timeline of events that uses and explains the evidence that has been gathered by the investigation team. Construction of the timeline helps identify information gaps that would require seeking additional evidence.

The timeline begins with one or more intimating events followed by subsequent events, such as safety system failures, that allowed the event sequence to continue (i.e., contributing causes).

One goal is to identify the root causes of the incident. These are typically management system failures such as incorrect operating procedures, lack of training, deficiencies in maintenance practices, and so on. Correcting such root causes might not only prevent reoccurrence of the specific incident or near miss being investigated but could also prevent other incidents or near misses.

Once the initiating and contributing causes have been identified, the investigation team should propose recommendations for how to prevent reoccurrence of those causes.

8.10.6*

A written report of the investigation shall be prepared that describes the incident, lists what has been learned from the investigation, and makes recommendations to prevent reoccurrence of that or similar incidents.

A.8.10.6

Incident reports should include the following information:

(1) Date of the incident

(2) Location of the incident and equipment/process involved

(3) Description of the incident, contributing factors, and the ~~suspected~~ identified cause(s)

(4) ~~Operation~~ Description of operation of automatic/manual fire protection systems and emergency response

(5) Any recommendations ~~and~~ for corrective actions taken or to be taken to prevent a reoccurrence

(6) Identification of the persons who conducted the investigation

The draft report should be reviewed with the health and safety committee, where appropriate, to allow input on the findings and the recommendations. Any recommendations from the safety and health committee should be communicated to the appropriate persons for corrective action, included in the management review, and considered for continual improvement activities.

The draft report should be reviewed and approved by management. It is management's responsibility to determine which recommendations they will endorse for implementation.

8.10.7*

A system shall be established to address and resolve the findings and recommendations.

A.8.10.7

Resolving a recommendation requires the identification and timely implementation of the action item(s) needed to achieve the intent of the recommendation. Such action items should be assigned to a specific individual, rather than a functional group, with explicit deadlines for implementation.

Action items should be tracked to implementation, with actual completion dates documented. Deadlines can be extended for compelling reasons, but such extensions should require formal approval from management and should be limited in number. The action-item tracking system should include provision for monitoring reassignment of responsibility when this occurs due to changes in personnel, and so on.

Action items should not be closed out based upon the promise of subsequent activities (i.e., the intended result of the action item should be physically in place before the action item is considered satisfied). Follow-up inquiry might be warranted to assess and monitor the effectiveness of actions taken.

Reports produced by external investigation agencies should be acted upon in the same manner as internal investigations.

8.10.8*

The investigation findings and recommendations shall be reviewed with affected personnel.

A.8.10.8

Investigation reports should be reviewed with all affected personnel (including contract employees where applicable) whose job tasks are relevant to the incident findings. The term *affected personnel* is also intended to include members of employee organizations such as health and safety committees and employee representatives of various types.

If requested, incident investigation reports should be made available to affected employees and their representatives at no cost.

The incident report should ~~also be reviewed with appropriate management personnel and~~ be retained on file for future reference. Incident reports are useful in support of the periodic DHA required by 7.1.4. The owner/operator should ~~consider retaining~~ retain the incident investigation reports for at least 5 years to be consistent with the DHA review schedule and in accordance with A.8.13.1(3) .

The owner/operator should consider sharing relevant learnings with other facilities within the company.

Supplemental Information

File Name	Description	Approved
660_FR_40_8.10.docx		
660_FR_40_8.10.docx	For prod use	

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Mon Feb 09 12:03:33 EST 2026

Committee Statement

Committee Statement: Most of the material from A.8.10 was relocated to other annex sections in this revision because it more appropriately aligned with other paragraphs.

New text has been added to A.8.10.1 to provide users with a list of the types of AHJs that are apt to be involved depending on the gravity of the event, and to emphasize that the incident investigation system should be sufficiently flexible to address a range of incident severities and complexities.

Text was removed from A.8.10.2 that is now covered in A.8.10.4.

The language previously in 8.10.3 was split up into two related but distinct activities, and to provide additional guidance as annex content to each new section. The focus of 8.10.3 has been narrowed to securing the scene and collecting evidence, while 8.10.4 focuses on investigation team make-up and 8.10.5 on identification of causes.

A.8.10.3 emphasises the importance of taking steps to ensure that critical evidence is not removed or altered before the investigation can commence. It provides a recommendation that the structural stability of the scene be evaluated before personnel access is permitted, and provides additional guidance for control of the incident scene as part of the effort to protect evidence. It also identifies key activities that are commonly included in efforts to collect evidence to support the investigation.

New paragraph 8.10.4 focuses on the identification of the investigation team and clarifies the role of the person having responsibility for coordinating the investigation. This might or might not be the person leading the investigation team. Annex material in A.8.10.4 provides guidance on identification and qualifications of the investigation team lead and team members, emphasizes the importance of establishing the objectivity of the investigation leader and team so that the investigation produces unbiased conclusions, details the expertise and expertise that would typically be required for the investigation teams, and emphasizes that expertise needs can vary depending upon the complexity/ severity of the event.

New paragraph 8.10.5 and annex material was added to address analysis of evidence, identification of causal factors, and proposal of recommendations.

New annex was added to 8.10.7 to provide additional guidance on resolving report recommendations and tracking them to their final implementation.

Note: The revision to paragraph A.8.10.8 regarding the time to retain an incident report is being balloted separately as First Revision 41.

Response Message: FR-40-NFPA 660-2026

Public Input No. 105-NFPA 660-2025 [Chapter 11]

First Revision No. 23-NFPA 660-2026 [Section No. 8.12.1]

8.12.1*

The owner/operator shall perform an operational readiness ~~reviewbefore~~ review before the start-up of the following:

(1) New facilities

(2) Modified facilities when the modification is significant enough to require change in the process and technology information required by 8.13.1(5)

(3) Facilities that have been shut down for minor maintenance activities

(4) Facilities that are periodically shut down as part of normal operations

(5)* Facilities that have been shut down for extended periods of time

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 10:35:04 EST 2026

Committee Statement

Committee Statement: Added a space between the words "review" and "before".

Response Message: FR-23-NFPA 660-2026

Public Input No. 88-NFPA 660-2025 [Section No. 8.12.1]

First Revision No. 24-NFPA 660-2026 [Section No. 9.4.1.1]

See FR-25

9.4.1.1

Where used to handle combustible particulate solids, systems shall be designed by ~~and installed under the supervision of~~ a qualified persons ~~who are knowledgeable about these systems and their associated hazards~~ .

9.4.1.2

Systems shall be installed under the supervision of qualified persons in accordance with drawings and specifications to achieve the design intent.

Supplemental Information

File Name	Description	Approved
660_FR-24_9.4.1.1.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 10:56:18 EST 2026

Committee Statement

Committee Statement: The definition of "qualified person" already covers the deleted text. It is important that a qualified person confirms that the design intent has been achieved. The qualified person could be a facility employee, as long as they have the proper knowledge and skills.

Response Message: FR-24-NFPA 660-2026

First Revision No. 26-NFPA 660-2026 [Section No. 9.4.2.3]

9.4.2.3

Openings provided specifically for inspection or ~~necessary process intake or discharge~~ for introducing or removing material from the process shall be permitted, provided they ~~too~~ do not permit fugitive dust release.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 11:17:15 EST 2026

Committee Statement

Committee Statement: This revision clarifies the intent of the requirement with no technical change.

Response Message: FR-26-NFPA 660-2026

Public Input No. 67-NFPA 660-2025 [Section No. 9.4.2.3]

First Revision No. 28-NFPA 660-2026 [Section No. 9.4.9.5]

9.4.9.5 Access Doors and Openings.

Where provided to permit inspection, cleaning, and maintenance, access doors and access openings shall meet the following requirements:

(1) They shall be designed to prevent dust leaks.

(2) They shall be permitted to be used as deflagration vents if they are specifically designed for both purposes.

(3)* They shall be bonded and grounded.

(4) If not designed to be used as deflagration vents, they shall be designed to be at least the same strength as the ~~AMS~~ enclosure .

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 13:32:47 EST 2026

Committee Statement

Committee Statement: This requirement is in the bulk storage enclosure section and should not have referenced AMS. This revision also makes it clear that the access door can be designed to be stronger than the enclosure per NFPA 68.

Response Message: FR-28-NFPA 660-2026

Public Input No. 66-NFPA 660-2025 [Section No. 9.4.9.5]

First Revision No. 29-NFPA 660-2026 [Section No. 9.4.14]

9.4.14 Bucket Elevators.

~~For requirements on bucket elevators, see industry- or commodity-specific chapters.~~

9.4.14.1

No bearings shall be located in the bucket elevator casing.

9.4.14.2

For additional requirements on bucket elevators, see industry- or commodity-specific chapters.

Supplemental Information

File Name	Description	Approved
660_FR-29_9.4.14.docx		

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 13:53:18 EST 2026

Committee Statement

Committee Statement: This requirement was previously in NFPA 652, 654, and 484 and is fundamental to all types of combustible dusts. Locating bearings in bucket elevator casings is a combustible dust hazard and should not be permitted.

Response Message: FR-29-NFPA 660-2026

Public Input No. 75-NFPA 660-2025 [Section No. 9.4.14]

First Revision No. 38-NFPA 660-2026 [Section No. 9.6.6]

9.6.6* Electrostatic Discharges.

A.9.6.6

Several types of electrostatic discharges are capable of igniting combustible dusts and hybrid mixtures. The requirements in 9.6.6 are intended to protect against the following four types of discharge: brush, cone (or bulking brush), propagating brush, and capacitive spark.

Brush discharges occur when electrostatic charge accumulates on a nonconductive surface and is discharged to a nearby conductor. These discharges have a maximum ~~theoretical~~ effective discharge energy of 3 mJ–5 mJ, which is sufficient to ignite most flammable vapors and gases. There are no records of brush discharges igniting combustible dusts outside of laboratory settings. In the first edition of NFPA 652, a 3 mJ MIE limit was applied as a minimum criterion for the use of nonconductive system components. The intent of this criterion was to ensure that brush discharges were prevented when the MIE was less than the ~~theoretical~~ upper limit of brush discharge energy. However, even where combustible dusts have MIE values less than 3 mJ, the diffuse nature of a brush discharge makes it a less effective ignition source than the capacitive spark used for determining the MIE value.

Cone or bulking brush discharges occur when resistive solids are transferred into containers where the charge accumulates in the bulk material. The compaction of the charges by gravity creates a strong electric field across the top surface of the material. When the field strength exceeds the breakdown voltage of air, a cone discharge occurs across the surface of the pile terminating at a conductive object (typically the vessel wall.) The energy of a cone discharge is dependent on the particle size and the diameter of the container (among other parameters), and discharges up to 20 mJ can occur in process equipment. ~~One particular situation in which cone discharges can occur is in filling FIBCs. For nonconductive containers and vessels such as FIBCs, discharges can occur across the full width (as opposed to the radius or half-width for conductive vessels). For a typical nonconductive FIBC, discharges up to 3 mJ can occur.~~

Propagating brush discharges occur when the rapid flow of particulate material generates a high surface charge on a thin nonconductive surface. The presence of this charge on one side of the material induces an opposite charge on the other side, essentially forming a capacitor. If the voltage difference across the material exceeds the material's breakdown voltage, then a pinhole channel is created at a weak spot in the material, and the charges on the opposite surfaces are discharged through the channel. Propagating brush discharge energy can be on the order of 1000 mJ. Propagating brush discharges cannot occur if the material is sufficiently thick (greater than 8 mm) or has a sufficiently low breakdown voltage (less than 4 kV for films or sheets or less than 6 kV for woven materials). The presence of an external grounding wire on a nonconductive object will not prevent a propagating brush discharge.

Capacitive spark discharges occur when the voltage difference between two conductive objects exceeds the breakdown voltage of the medium between them (typically air). Capacitive sparks can ignite both flammable vapors/gases and combustible dusts.

For more information on electrostatic discharges, refer to NFPA 77 and IEC TS 60079-32-1, *Explosive atmospheres — Part 32-1: Electrostatic hazards, guidance*.

9.6.6.1 Conductive Equipment.

9.6.6.1.1

Particulate handling equipment shall be conductive unless the provisions of 9.6.6.1.2and 9.6.6.1.4 , where applicable, are ~~applicable~~ satisfied .

9.6.6.1.2

Nonconductive system components shall be permitted where all of the following conditions are met:

(1)* Hybrid mixtures and flammable gas/vapor atmospheres are not present.

(2)* Conductive particulate solids are not handled.

(3)* The nonconductive components do not result in isolation of conductive components from ground.

(4)* The breakdown strength across nonconductive sheets, coatings, membranes, or pipe/ vessel wall with thickness less than 0.3 in. (8 mm) does not exceed 4 kV, and the breakdown strength across nonconductive woven materials does not exceed 6 kV, when used in high surface charging processes.

9.6.6.1.3*

Bonding and grounding with a resistance of less than 1.0×10^6 ohms to ground shall be provided for conductive components.

9.6.6.1.4* Flexible Connectors.

Detail FR-39

~~**9.6.6.1.4.1***~~

~~This section shall not be required to be applied retroactively.~~

9.6.6.1.4.1*

Flexible connectors used for pneumatic conveying, dust collection, or vacuum cleaning, regardless of length, shall have ~~an end-to-end~~ a resistance to ground of less than 1.0×10^6 ohms ~~even where an internal or external bonding wire connects the equipment to which the flexible connector is attached~~ from the worst-case location on the inside surface of the connector .

A.9.6.6.1.4.1

Flexible connectors can produce electrostatic ignition hazards in multiple ways. Where they connect two conductive objects, flexible connectors can introduce a resistance to bonding and grounding of the objects on either end, creating the potential for capacitive spark discharges. This hazard is typically addressed through the use of a dedicated bonding jumper or by connecting a metallic spiral reinforcement wire to the couplings on both ends of the flexible connector. Even where all conductive objects are bonded and grounded, a flexible connectors can create propagating brush discharges through the connector itself. For a propagating brush discharge to occur, a voltage in excess of 4 kV must accumulate on the surface of the connector. Such a voltage can be generated when conveying dusts and particulate solids. The 10^6 ohms limit is based on a streaming current calculation. Per Glor (1988), the charge to mass ratio for resistive particulate solids is on the order of 1 x 10^{-4} C/kg. Additional guidance on charge-to-mass ratios for common processes can be found in NFPA 77 . With a conveying rate on the order of 22 lb/sec (10 kg/sec) *(see A.9.6.6.2)*, the streaming current would be 10^{-3} C/sec (amps). At this current level, the voltage that could be generated by a resistance of 10^6 ohms would be 1 kV, which is low enough to prevent propagating brush discharges from occurring. ~~The streaming current calculation method could be used to support an alternate end-to-end resistance threshold as part of a risk assessment for a specific conveying application.~~

The resistance to ground for a given flexible connector can be determined using the test method in ISO 8031, *Rubber and plastics hoses and hose assemblies — Determination of electrical resistance and conductivity* . Static dissipative flexible connectors having a grounded spiral reinforcing wire primarily dissipate charge from the inside surface through the body of the flexible connector to the reinforcing wire. This results in a shorter path to ground through the connector material and a resistance to ground that is (relatively) independent of the connector length. Static dissipative flexible connectors without a grounded spiral reinforcing wire dissipate charge along the length of the connector, both through the volume of the connector and across the inner surface. For these connectors, the resistance to ground is dependent on the length of the connector.

(A)*

Where the flexible connector contains a grounded conductive spiral reinforcing wire, the resistance shall be determined between the inside surface and the conductive spiral reinforcing wire.

A.9.6.6.1.4.1(A)

The determinations of resistance to ground can be made by physical measurement or by calculation using resistance data provided by the hose manufacturer.

(B)*

Where the flexible connector does not contain a grounded conductive spiral reinforcing wire, the resistance shall be determined from the farthest point on the inside surface of the flexible connector to a conductive object at the end of the hose.

A.9.6.6.1.4.1(B)

For a flexible connector with grounded metallic connections on both ends, the farthest point will be at the midpoint of the connector. Where only one end has a grounded connection, the farthest point will be at the opposite end. See also, A.9.6.6.1.4.1(A) .

9.6.6.1.4.2*

Where supported by calculation of streaming current and accumulated voltage, an alternative resistance-to-ground value shall be permitted to be used.

A.9.6.6.1.4.2

The streaming current calculation method could be used to support an alternate end-to-end resistance threshold as part of a risk assessment for a specific conveying application. Testing can be conducted to determine the actual charge-to-mass ratio for a given material instead of the value given in A.9.6.6.1.4.1 . Also, the calculation provided in A.9.6.6.1.4.1 uses a conservatively high product conveying rate of 22 lb/sec (40 tons per hour). The streaming current is directly proportional to the conveying rate (on a mass basis), so a lower conveying rate would allow for a higher resistance limit in flexible connectors. Table A.9.6.6.1.4.2 provides the calculated resistance limits for a variety of flows. When determining the actual flow rate, consideration should be given to transient high-flow conditions.

Table A.9.6.6.1.4.2 Maximum Allowable Resistance to Ground for Flexible Connectors

Note 1	**Note 2**		**Note 3**	**Note 4**	**Note 5, Note 6, Note 7**
Charge Density	**Mass Flow Rate**		**Streaming Current**	**Max. Allowable Voltage**	**Max. Allowable Resistance to Ground**
C/kg	**Kg/s**	**Ton/hr.**	**A**	**V**	**Ohm**
1×10^{-4}	0.01	0.036	1.0×10^{-6}	4,000	4.0×10^{9}
1×10^{-4}	0.1	0.36	1.0×10^{-5}	4,000	4.0×10^{8}
1×10^{-4}	0.2	0.72	2.0×10^{-5}	4,000	2.0×10^{8}
1×10^{-4}	0.5	1.8	5.0×10^{-5}	4,000	8.0×10^{7}
1×10^{-4}	1	3.6	1.0×10^{-4}	4,000	4.0×10^{7}
1×10^{-4}	2	7.2	2.0×10^{-4}	4,000	2.0×10^{7}
1×10^{-4}	4	14.4	4.0×10^{-4}	4,000	1.0×10^{7}
1×10^{-4}	6	21.6	6.0×10^{-4}	4,000	6.7×10^{6}
1×10^{-4}	8	28.8	8.0×10^{-4}	4,000	5.0×10^{6}
1×10^{-4}	10	36	1.0×10^{-3}	4,000	4.0×10^{6}
1×10^{-4}	15	54	1.5×10^{-3}	4,000	2.7×10^{6}
1×10^{-4}	20	72	2.0×10^{-3}	4,000	2.0×10^{6}
1×10^{-4}	25	90	2.5×10^{-3}	4,000	1.6×10^{6}
1×10^{-4}	30	108	3.0×10^{-3}	4,000	1.3×10^{6}

Notes:

1. Conservative (high) charge density (charge-to-mass ratio) for resistive particulate solids is on the order of 1×10^{-4} C/kg (Glor 1988)

2. Mass flow rate through the flexible connector

3. Streaming current = charge density (C/kg) × mass flow rate (kg/s)

4. Minimum surface voltage required for generation of propagating brush discharge (IEC TC 60079-32-1)

5. Using Ohm's law, max. allowable resistance (*R*) = 4,000 (*V*)/streaming current (*I*)

6. Measurement of resistance to ground (resistance through inner layer surface of the hose to grounding wire or end-to-end resistance) is measured according to ISO 8031, *Rubber and plastics hoses and hose assemblies — Determination of electrical resistance and conductivity*

7. Other max. resistance-to-ground values are allowed for conditions giving rise to charge

densities and mass flow rates other than those shown in this table. Maximum allowable resistance to ground is calculated using the equations in Notes 3 and 6.

9.6.6.1.4.3*

Flexible connectors used for gravity or mechanical conveying, regardless of length, shall have ~~an end-to-end~~ a resistance to ground of less than 1.0 x 10^8 ohms ~~even where an internal or external bonding wire connects the equipment to which the flexible connector is attached~~ from the worst-case location on the inside surface of the connector .

A.9.6.6.1.4.3

The resistance limit of 10^8 ohms for gravity and mechanical conveying is less stringent than the limit for pneumatic conveying, dust collection, and vacuum cleaning due to the lower charge generation rates in gravity and mechanical conveying. See also, A.9.6.6.1.4.1(A) .

9.6.6.1.4.4*

Where flammable vapors are not present, flexible connectors with a resistance equal to or greater than 1.0 × 10^8 ohms shall be permitted under either of the following conditions:

(1) The dust has an MIE greater than ~~2000~~ 1000 mJ.

(2) The maximum powder transfer velocity is less than 2000 ft/min (10 m/sec).

A.9.6.6.1.4.4

Propagating brush discharges, which are generally considered to be the most energetic type of electrostatic discharge in industrial applications, are widely accepted to be capable of producing effective energies on the order of 1000 mJ. ~~However, high~~ High charging applications involving large surface areas are theoretically capable of creating propagating brush discharges with energies exceeding 1000 mJ, but the incendivity of a propagating brush discharge might not be as high as a capacitive spark having the same energy . ~~Subsection 9.6.6.1.4.4 establishes a limit of 2000 mJ to account for such instances and allow for commercially available testing to determine if a dust MIE is greater than 2000 mJ.~~ While this guidance is expected to be appropriate for most industrial applications, special care should always be taken to evaluate the process as part of the DHA to verify that insulative flexible connectors do not present an ignition hazard.

9.6.6.2* Maximum Particulate Transport Rates.

For requirements on this subject, see industry- or commodity-specific chapters.

9.6.6.3* Grounding of Personnel.

9.6.6.3.1*

Where an explosible atmosphere exists and is subject to ignition from an electrostatic spark discharge from ungrounded personnel, personnel involved in manually filling or emptying particulate containers or vessels shall be grounded during such operations.

9.6.6.3.2

Personnel grounding shall not be required where both of the following conditions are met:

(1) Flammable gases, vapors, and hybrid mixtures are not present.

(2)* The minimum ignition energy of the dust cloud is greater than 30 mJ.

9.6.6.4* Flexible Intermediate Bulk Containers (FIBCs).

FIBCs shall be permitted to be used for the handling and storage of combustible particulate solids in accordance with the requirements in 9.6.6.4.1 through 9.6.6.4.7.

9.6.6.4.1*

Electrostatic ignition hazards associated with the particulate and objects surrounding or inside the FIBC shall be included in the DHA required in Chapter 7.

9.6.6.4.2*

Type A FIBCs shall be limited to use with noncombustible particulate solids or combustible particulate solids having an MIE greater than 1000 mJ.

9.6.6.4.2.1

Type A FIBCs shall not be used in locations where flammable vapors are present.

9.6.6.4.2.2*

Type A FIBCs shall not be used with conductive dusts.

9.6.6.4.3*

Type B FIBCs shall be permitted to be used where combustible dusts having an MIE greater than 3 mJ are present.

9.6.6.4.3.1

Type B FIBCs shall not be used in locations where flammable vapors are present.

9.6.6.4.3.2

Type B FIBCs shall not be used for conductive dusts. *(See A.9.6.6.4.2.2.)*

9.6.6.4.4*

Type C FIBCs shall be permitted to be used with combustible particulate solids and in locations where Class I Group C/D or Zone Group IIA/IIB flammable vapors or gases, as defined by *NFPA 70*, are present.

9.6.6.4.4.1

Conductive FIBC elements shall terminate in a grounding tab, and resistance from these elements to the tab shall be less than or equal to 10^7 ohms.

9.6.6.4.4.2

Type C FIBCs shall be grounded during filling and emptying operations with a resistance to ground of less than 25 ohms.

9.6.6.4.4.3

Type C FIBCs shall be permitted to be used for conductive dusts where a means for grounding the conductive dusts is present.

9.6.6.4.5*

Type D FIBCs shall be permitted to be used with combustible particulate solids and in locations where Class I Group C/D or Zone Group IIA /IIB flammable vapor or gases, as defined by *NFPA 70*, having an MIE greater than 0.14 mJ are present.

9.6.6.4.5.1*

Type D FIBCs shall not be permitted to be used for conductive particulate solids.

9.6.6.4.6*

Type B, Type C, and Type D FIBCs shall be tested and verified as safe for their intended use by a recognized testing organization in accordance with the requirements and test procedures specified in IEC 61340-4-4, *Electrostatics — Part 4-4: Standard Test Methods for Specific Applications — Electrostatic Classification of Flexible Intermediate Bulk Containers (FIBC)*, before being used in hazardous environments.

9.6.6.4.6.1

Intended use shall include both the product being handled and the environment in which the FIBC will be used.

9.6.6.4.6.2

Materials used to construct inner baffles, other than mesh or net baffles, shall meet the requirements for the bag type in which they are to be used.

9.6.6.4.6.3*

Where used, inner liners shall be suitable to maintain the electrostatic characteristics of the bag types in which they are used.

9.6.6.4.6.4

Documentation of test results shall be made available upon request of the AHJ.

9.6.6.4.6.5

FIBCs that have not been tested and verified for type in accordance with IEC 61340-4-4, *Electrostatics — Part 4-4: Standard Test Methods for Specific Applications — Electrostatic Classification of Flexible Intermediate Bulk Containers (FIBC)*, shall not be used for combustible dusts or in flammable vapor atmospheres.

9.6.6.4.7*

Deviations from the requirements in 9.6.6.4.1 through 9.6.6.4.6 for safe use of FIBCs shall be permitted based on a documented risk assessment in accordance with Section 9.2.

9.6.6.5 Rigid Intermediate Bulk Containers (RIBCs).

9.6.6.5.1*

Conductive RIBCs shall be permitted to be used for dispensing into any flammable vapor, gas, dust, or hybrid atmospheres provided that the RIBCs are electrically grounded.

9.6.6.5.2*

Nonconductive RIBCs shall not be permitted to be used for applications, processes, or operations involving combustible particulate solids or where flammable vapors or gases are present unless a documented risk assessment of the electrostatic hazards is completed in accordance with Section 9.2.

Supplemental Information

File Name	Description	Approved
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Submitter Information Verification

Committee: CMD-FUN

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Committee Statement

Committee Statement: Note: There is a separate revision (FR 39) that deletes 9.6.6.1.4.1 and A.9.6.6.1.4.1. This ballot item, FR 38, makes the other changes to 9.6.6.

Changes were made to section 9.6.6 and its annex to address the use of nonconductive equipment.

Section 9.6.6.1 was modified to specifically reference section 9.6.6.1.4 regarding flexible connectors where applicable, in response to PI 167. Note that the other changes proposed in PI 167 were not incorporated as the sections referenced did not refer to "equipment" in this context but rather personnel, containers, and industrial trucks.

Section 9.6.6.1.4.2 was modified to clarify the requirements for flexible connectors. A resistance to ground was specified instead of an end-to-end resistance value to better represent the critical variable in defining the potential for a propagating brush discharge. Additional subsections were added, along with annex text, to differentiate between flexible connectors having a grounded reinforcing wire and those without, as the resistance to ground may be determined differently for each case. The annex text for 9.6.6.1.4.2 was expanded to reference NFPA 77 for charge to mass ratios for process operations and ISO 8031 for testing of flexible conductors. Further explanation of the difference between connectors with and without grounded reinforcing wires was also provided.

Public Inputs 48, 49 and 98 proposed similar revisions for this section. PIs 48 and 49 proposed differentiating between conductive and antistatic flexible connectors, but the clarification of the resistance determination was deemed to be a better way to address the issue. Furthermore, PI 49 was overly prescriptive in the requirements for antistatic flexible connectors. PI 98 proposed adding a volume resistivity limit which would have created a second requirement within a single section, and this concern was addressed with the addition of 9.6.6.1.4.2(a).

A new section was added before 9.6.6.1.4.3 to explicitly allow for calculation of an alternative resistance to ground limit. This was done in recognition of the high material transfer rate that was assumed in defining the prescriptive resistance limit and to allow users to apply a different limit based on process-specific data. A table was provided to demonstrate the use of this alternative methodology.

The language in Section 9.6.6.1.4.3 (now 9.6.6.1.4.4) was modified to align with the changes made to 9.6.6.1.4.2 for consistency.

Section 9.6.6.1.4.4 (now 9.6.6.1.4.5) was revised to change the MIE threshold from 2000 mJ to 1000 mJ, as proposed in PI 168, with explanatory annex text. This is consistent with PI 168 and 169. This is consistent with Britton (1999) as a primary reference. The alternate reference provided in the substantiation for PI 168 and the proposed annex for PI 169 made reference to the incendivity of propagating brush discharges but did not demonstrate or quantify the issue beyond what was addressed in the Britton reference.

Response Message: FR-38-NFPA 660-2026

Public Input No. 48-NFPA 660-2025 [Section No. 9.6.6.1.4.2]

Public Input No. 169-NFPA 660-2026 [Section No. A.9.6.6.1.4.4]

Public Input No. 167-NFPA 660-2026 [Section No. 9.6.6.1.1]

Public Input No. 98-NFPA 660-2025 [Section No. 9.6.6.1.4.2]

Public Input No. 168-NFPA 660-2026 [Section No. 9.6.6.1.4.4]

First Revision No. 31-NFPA 660-2026 [Chapter 10]

Chapter 10 Emergency Planning and ~~Response~~ Manual Firefighting

10.1 Retroactivity.

This chapter and the corresponding *X*.10 sections of the industry- and commodity-specific chapters shall be applied retroactively to new and existing facilities and processes.

10.2 Emergency Planning and Response ~~Plan~~ .

10.2.1*

A written emergency response plan shall be developed for preparing for and responding to work-related emergencies including, but not limited to, fires, flash fires, and explosions.

~~**10.2.1.1**~~

~~The emergency response plan shall be available on-site or electronically.~~

~~**10.2.1.2**~~

~~The emergency response plan shall include, but not be limited to, the following:~~

- * ~~A means of notification for occupants in the event of fire and explosion~~

  ~~**A.10.2.3(1)**~~ –

  ~~Guidance for notification systems can be found in 29 CFR 1910.165, 29 CFR 1910.38, and *NFPA 72* .~~

- ~~A preplanned evacuation assembly area~~
- ~~A person(s) designated to notify emergency responders, including the fire department~~
- ~~A facility layout drawing(s) showing egress routes, hazardous chemical locations, and fire protection equipment~~
- ~~Location of a safety data sheet(s) for hazardous chemicals~~
- ~~An emergency telephone number(s)~~
- ~~Emergency response duties for occupants~~
- ~~A person(s) designated to meet the offsite emergency responder(s) to coordinate the incident~~

10.2.2

Emergency planning and response shall be in accordance with NFPA 600 and NFPA 1660 .

10.2.3

The emergency response plan shall include, but not be limited to, the following:

(1)* A means of notification for occupants in the event of fire and explosion

A.10.2.3(1)

Guidance for notification systems can be found in 29 CFR 1910.165, 29 CFR 1910.38, and *NFPA 72*.

(2) A preplanned evacuation assembly area

(3) A person(s) designated to notify emergency responders, including the fire department

(4) A facility layout drawing(s) showing egress routes, hazardous chemical locations, and fire protection equipment

(5) Location of a safety data sheet(s) for hazardous chemicals

(6) ~~An~~ Plant management emergency telephone number(s)

(7) Emergency response duties for occupants

(8) A person(s) designated to meet the offsite emergency responder(s) to coordinate the incident

(9) Interdepartmental and interplant cooperation

(10) Cooperation of outside agencies

(11) The release of accurate information to the public

10.2.4

The emergency response plan shall address locations for remote shutoff of supply systems where any of the following are present:

(1) Water (water from all types of sources)

(2) Electrical materials

(3) Flammable gases

(4) Ignitable (flammable or combustible) liquids

(5) Toxic materials

(6) Other hazardous materials

~~**10.2.2**~~

~~The emergency response plan and procedures shall be reviewed and validated at least annually and as required by process changes.~~

~~**10.2.3**~~

~~The emergency response plan shall be shared with relevant local community officials and emergency response agencies.~~

10.3 ~~Reserved~~ Emergency Response Plan and Training .

10.3.1

Employee health and safety in operations shall depend on the recognition of actual or potential hazards, the control or elimination of those hazards, and the training of employees on safe working procedures.

10.3.2

The emergency response plan shall be available on-site or electronically.

10.3.3

Fires, when discovered, shall be reported promptly to facility management and emergency responders, including the fire department.

10.3.4

If a fire cannot be controlled promptly in its incipient stage, the endangered structure(s) shall be evacuated.

10.3.5

~~The emergency response plan and procedures shall be reviewed~~ Emergency drills shall be both performed annually by plant personnel and validated ~~at least annually and~~ as required by process changes.

10.3.6

Plant personnel, including management, supervisors, and maintenance and operating personnel, shall be trained to participate in plans for controlling plant emergencies.

10.3.7

The emergency response plan shall be shared with relevant local community officials and emergency response agencies.

10.3.8

Malfunctions of the process shall be simulated and emergency actions undertaken as necessary.

10.3.9

Disaster drills that simulate a major catastrophic situation shall be undertaken periodically with the cooperation and participation of public fire, police, and other local community emergency units and nearby cooperating plants.

10.3.10*

Specialized training for the public fire department(s) and industrial fire brigades shall be warranted when the facility-specific hazards dictate that the methods to control and extinguish a fire are outside of their normal arena of traditional firefighting.

A.10.3.10

See OSHA's *Firefighting Precautions at Facilities with Combustible Dust* for additional information.

10.4 Manual Firefighting.

10.4.1*

Those individuals responsible for manual fire suppression shall have a fire protection plan.

A.10.4.1

This plan should meet the recommendations contained in the National Grain and Feed Association Research Report, "Emergency Preplanning and Fire Fighting Manual - A Guide for Grain Elevator Operators and Fire Department Officials," or other industry- or commodity-specific guide.

10.4.2*

Proper protective clothing, respiratory protection, and adequate eye protection shall be used by all responding firefighting personnel equipped to the requirements of NFPA 600 (if applicable) or NFPA 1081 and assigned to a combustible metal fire.

A.10.4.2

Burning combustible metals will burn through material used in the construction of most firefighter protective clothing. Some features (e.g., heavy quilted linings, aluminized outer shells) can reduce this risk. The self-contained breathing apparatus (SCBA) facepiece eye protection worn by firefighters adequately protects against the effects of a lithium fire, with the exception of the intense light given off by burning lithium. *(See NFPA 1500 .)*

Specific testing indicates that white-light levels emitted from burning lithium exceed recommended levels, and extended lithium fire experience has shown that this intense light can cause serious damage to unprotected eyes. A clip-on adapter over an SCBA facepiece with a shaded glass lens equivalent to a No. 6 welding lens has been used successfully to reduce such hazards. A darker lens tends to obstruct the firefighter's view to an unacceptable degree.

10.4.3*

The evaluation of the risk to facility personnel and firefighters shall be made based on discussions with the responding fire department(s) and review of the DHA.

A.10.4.3

Manual firefighting could pose an unacceptable risk to facility personnel and emergency responders.

10.4.4

The potential effectiveness of manual firefighting shall be assessed by experienced firefighting personnel after reviewing the hazard assessment documentation developed in accordance with the DHA.

10.4.5

For materials that can be effectively extinguished with water, hose streams shall be used with great care to avoid creating dust clouds or causing structural damage to bins.

10.4.5.1

Straight stream nozzles shall not be used on fires in areas where dust clouds can be generated.

10.4.5.2

Fire responders shall be cautioned where using straight stream nozzles in the vicinity of combustible dust accumulations that dust clouds can be formed and can be ignited by any residual smoldering or fire.

10.4.5.3*

Fog nozzles or portable spray hose nozzles that are listed or approved for use on Class C fires shall be provided in areas that contain dust to limit the potential for generating unnecessary airborne dust during firefighting operations.

A.10.4.5.3

A nozzle listed or approved for use on Class C fires produces a fog discharge pattern that is less likely than a straight stream nozzle to suspend combustible dust, which could otherwise produce a dust flash fire or explosion potential.

10.4.5.4

Straight stream nozzles or combination nozzles shall be permitted to be used to reach fires in locations that are otherwise inaccessible with the nozzles specified in 10.4.5.3 .

10.4.6

Where firefighting water or wet product can accumulate in the system, the vessel, pipe supports, and drains shall be designed to support the additional water weight in accordance with NFPA 91 .

10.5 Firefighting Operations and Activities.

Incipient firefighting techniques shall be established for fighting different types of fires that might be present at a facility, including those in 10.5.1 through 10.5.9 .

10.5.1 Clothing Fires.

10.5.1.1

Emergency procedures for handling clothing fires shall be established as part of the plan.

10.5.1.2

If deluge showers are installed, they shall be located away from dry metal powder–processing and metal powder–handling areas if water is not an effective extinguishing agent.

10.5.1.3

The plan shall address locations for remote shutoff of supply systems where any of the following are present:

(1) Water (water from all types of sources)

(2) Electrical materials

(3) Flammable gases

(4) Ignitible (flammable or combustible) liquids

(5) Toxic materials

(6) Other hazardous materials

10.5.1.4

In plant areas where water is excluded, fire blankets shall be distributed for extinguishing clothing fires.

10.5.2* Elevator Leg Fires.

A.10.5.2

Material flow into a leg should be stopped and the leg should be shut down. Leg fires should be extinguished by water fog or gentle application of water. Fires should be located by feeling the leg casing for heat or observing discoloration of metal. If the location is unknown, water should be applied first in the boot section, then in the bin-pulley access door, and last in the head section.

10.5.2.1

Burning material shall not be transferred into legs.

10.5.3* Conveyor Belt Fires.

A.10.5.3

The conveyor belt should be shutdown (halted). Conveyor belt fires should be extinguished by application of water. Material flow to the conveyor belt should be stopped. If necessary, the belt should be cut to isolate the fire.

10.5.4* Dryer Fires.

A.10.5.4

Dryer fires should be extinguished by removing burning material from the dryer or gentle application of water. Fuel to burners, fans, and material flow into the dryer and from the facility should be stopped. If necessary, emergency dump should be used to remove material from the dryer.

10.5.5* Concrete Bin or Silo and Steel Tank Fires.

A.10.5.5

Concrete bin or silo fires should be extinguished by wetting the top surface of the material with gentle application of water at a low flow rate directly to the burning materials, and then removal of burning material from the bin or silo directly to the outside. Fire should be located by thermometer probes, thermographic photography, or feeling heat on bin or silo surfaces. Openings to the bin or silo should be sealed to limit oxygen entry. Material flow to and from the bin or silo should be stopped. Firefighting operations should be done from outside the bin or silo. Fires should be isolated by selective unloading of material onto the ground.

10.5.6* Concrete Bin or Silo and Steel Tank Smolders.

A.10.5.6

A deep-seated smolder in a bin, tank, or silo should not be extinguished with water. The addition of water can generate CO that would build up in the bin and potentially explode [see 10.5.8]. A better approach is to inject inert gas (such as carbon dioxide or nitrogen) to displace the oxygen and smother the smolder.

10.5.7* Fumigant or Chemical Fires.

A.10.5.7

Fires involving fumigants containing phosphine should be extinguished by inert material or nonaqueous agent used for Class B fires. Water should not be used for phosphine fires to avoid exothermic reaction and development of explosive gases.

10.5.8* Water Gas Reaction.

A.10.5.8

Application of small amounts of water on glowing grain in a partially confined space, such as a grain silo, and in the presence of air can generate a water gas reaction. The glowing grain must be at a temperature of at least 1290°F to 1470°F (700°C to 800°C), and initial water contact might not cool the mass of glowing grain below 1110°F (600°C). The partial oxidation reduction between carbon and water forms carbon monoxide and hydrogen as shown in Equation A.10.5.8a.

$$C + H_2O \rightarrow CO + H_2 \quad \text{[A.10.5.8a]}$$

In the presence of oxygen (air), the carbon monoxide and hydrogen burn, immediately releasing heat as shown in Equation A.10.5.8b.

$$C + H_2O + O_2 \rightarrow CO_2 + H_2O + 19{,}440\ \mathrm{J/g}\ (8350\ \mathrm{Btu/lb}) \quad \text{[A.10.5.8b]}$$

In a partially confined space, the combustion energy will rapidly pressurize the space beyond what the silo walls or tops can withstand, causing destruction of the silo.

10.5.9 Bearing Fires.

10.5.9.1

Bearing fires shall be extinguished with a gentle application of water fog onto the bearing for cooling.

10.5.9.2

If water is not available, other means of extinguishment shall be permitted to be used on the bearing fire, provided caution is taken to avoid the suspension of combustible dust.

10.5.9.3

If the bearing is located inside equipment, all of the following shall apply:

(1) Material flow shall be stopped.

(2) Equipment shall be shut down.

(3) Extreme caution shall be used when equipment is opened.

10.6 Agricultural and Food Processing. (Reserved)

10.7* Combustible Metals.

A.10.7

The objectives in fighting combustible metal fires are isolation and containment, rather than extinguishment. Water and other liquids have proved ineffective in extinguishing combustible metal fires. Streams of water intensify most combustible metal fires by feeding it oxygen. There is also the possibility of causing a steam or hydrogen explosion, particularly if large amounts of combustible metal are involved. The great affinity of high-temperature combustible metal for oxygen frees a considerable amount of hydrogen, which can reach explosive concentrations in confined spaces. Entrapment of water under any burning or hot combustible metal can result in a steam explosion.

Because of their unique nature, combustible metal fires demand a comprehensive fire protection plan wherever combustible metal is processed, handled, used, or stored. This plan should include specific actions in the event of a combustible metal fire and should be coordinated with the local facility management, responding firefighters, and medical personnel.

The plan should recognize the extreme hazards associated with combustible metal–water reactions that might occur with sprinkler water. Specific attention should be given to an evacuation plan for personnel in the event of any release of water.

Properly trained personnel who work with combustible metal know its hazards. Such personnel are best equipped to extinguish a combustible metal fire in its incipient stage. Training should include sufficient information to determine whether extinguishment can be accomplished safely and effectively.

10.7.1

Local emergency response agency notification shall be required for any operation storing or processing 5 lb (2.27 kg) or more of powder, dusts, fines, or alkali metal in any form or 500 lb (227 kg) or more of chips or turnings.

10.7.2

The following list of actions to be performed as well as information regarding the hazards of combustible metals shall be provided to emergency responders for the safe handling of combustible metal fires:

(1) Perform a size-up, evaluation, and identification of metals involved in the fire.

(2) Ensure control of utilities (e.g., water, gases, power, and so on) to affected areas.

(3) Review safety data sheets (SDSs) for the involved products, and, if available, contact those familiar with the product and hazards.

(4) Evaluate whether the fire can be isolated safely and allowed to burn out.

(5) Determine whether uninvolved product and exposures — other than alkali metals — can be protected by hose streams, after an adequate review has been completed to ensure any runoff from hose streams does not come into contact with burning or molten combustible metal.

(6) Do not apply water to alkali metals in either a fire or nonfire situation.

(7) Use an inert blanket, such as argon, helium, or nitrogen, if the fire is burning in a closed container, such as a dust collection system, to control the fire where an adequate delivery system is available and personnel safety is considered.

(8) Evaluate the potential for explosion.

(9) Use extreme caution with fires involving combustible-metal powders, dusts, and fines because of the possibility of explosions, especially if the product becomes airborne and there is an available ignition source.

(10) Evaluate whether there is adequate drainage to prevent the contact of water with burning metal that is not compatible for protecting exposures.

(11) Evaluate the fire to determine whether the fire can burn itself out naturally to minimize hazards to personnel and losses to exposures.

(12) Evaluate the control and shutdown of both domestic and fire protection water systems to prevent unintended contact of water with burning or molten combustible metal.

(13) Use extinguishing agents that are compatible with the hazards present.

(14) Use extinguishing agents for containment of small and incipient fires.

(15) Use extreme caution with fires involving large quantities of product within structures.

(16) Most fires involving combustible metals cannot be extinguished in a manner other than by providing an inert atmosphere of argon or helium — and nitrogen for alkali metals or iron — if the product is dry.

(17) Most fires can be controlled by application of argon or helium — or nitrogen for alkali metals or iron— or by the development of an oxide crust.

(18) The temperature of the metals involved in the fire can remain extremely high and the fire can flare up again if the product is disturbed prior to complete oxidation of the product or self-extinguishment.

(19) Water in contact with molten combustible metals will result in violent steam explosions and can cause hydrogen explosions and reactions.

(20) Isolate the metal as much as possible; large fires might be impossible to extinguish.

(21) The physical state of the product, such as chips, powder, fines, and dust, and the quantity of product involved in the fire, potentially involved in the fire, or both, are extremely important factors for emergency responders.

(22) Fires involving large quantities of product within structures can result in rapid heat buildup and smoke generation beyond that normally encountered in fires involving ordinary combustibles.

10.7.3 Firefighting Activities.

10.7.3.1*

Trained employees shall be permitted to fight incipient-stage fires, provided the fire can be controlled with portable extinguishers or other dry extinguishing agents.

A.10.7.3.1

One of the greatest dangers to firefighters is the splattering effect of burning alkali metals. Molten alkali metal is very fluid and easily spread; therefore, extreme care needs to be taken when applying firefighting agent. The force used to deliver agent from an extinguisher can cause the molten alkali to splash to adjacent areas. Therefore, the delivery technique is very important. If direct agent application becomes hazardous, indirect application techniques should be used. Deflecting agent off another object or directing the agent stream above the hazard and letting the agent fall by gravity can be effective.

10.7.3.2*

In case of fire in reactive metal chips, turnings, or powder compact, the pan or tray shall not be disturbed or moved, except by an individual knowledgeable in the fire aspects of combustible metals, until the fire has been extinguished and the material has cooled to ambient temperature.

A.10.7.3.2

Forming a crust over burning alkali metals reduces the available oxygen and eliminates exothermic reactions. Extinguishing agent should first be applied to the white-hot burning areas, then evenly applied to the mass, controlling the flow to form an oxygen-depleting crust. Since alkali metal tends to flow easily through any weak spots, agents should be applied evenly to construct a continuous crust. If the alkali metal surfaces, additional agent should be applied to strengthen the crust.

Actual crust formation is created by the ability of some powdered agents to absorb heat from the alkali metals. In the case of copper powder, an alkali metal–copper alloy is formed as heat is absorbed from an alkali metal. Once the crust is formed, the temperature of the alkali metal decreases and exothermic reactions are reduced. Extreme care should be taken to ensure that the crust is not disturbed or broken until the temperature of the alkali metal is decreased to the point where resolidification occurs (or in the case of NaK, until the mass is at or near room temperature).

10.7.3.3

Combustible-metal fires beyond the incipient stage shall be fought by professional firefighters, specially trained fire brigade personnel, or both.

10.7.3.4

Once the fire is extinguished and a crust is formed, the crust shall not be disturbed until the residue has cooled to room temperature.

10.7.3.5

Fire residues shall be protected to prevent adverse reactions and to prevent the formation of reactive or unstable compounds.

10.7.3.6

Fire residues shall be disposed of in accordance with federal, state, and local regulations.

10.7.3.7

When drums or tote bins of burning materials can be moved safely, they shall be moved away from processing equipment and out of buildings as rapidly as possible.

10.7.4 Alkali Metals Firefighting Procedures.

10.7.4.1

While an alkali-metal fire is being fought, every effort shall be made to avoid splattering the burning alkali metals.

10.7.4.2

Once the fire is extinguished and a crust is formed, the crust shall not be disturbed until the residues have cooled to room temperature.

10.7.5 Firefighting Organization.

10.7.5.1

Only trained personnel shall be permitted to engage in fire control activity.

10.7.5.2

Personnel other than trained personnel shall be evacuated from the area.

10.7.5.3

Training shall emphasize the different types of fires anticipated and the appropriate agents and techniques to be used.

10.7.5.4

Firefighting personnel shall be given training in the extinguishment of test fires set in a safe location away from manufacturing buildings.

10.7.5.5

Training shall include all possible contingencies.

10.7.5.6*

If professional or volunteer firefighters are admitted onto the property in the event of a fire emergency, their activity shall be directed by a unified incident command that includes knowledgeable plant personnel.

A.10.7.5.6

It is recommended that a practice fire drill be conducted once each year to familiarize local fire department personnel with the proper methods of fighting Class D fires. Professional or volunteer firefighters from outside the plant cannot be expected to be trained for the specific fire and life hazards associated with metal powder and fires. In the interest of their own safety, they should be directed by the plant's safety officer or firefighting officer.

10.7.5.7

The following information on the safe handling of combustible metal fires shall be provided for emergency preparedness planning:

(1) Water, when applied to most burning combustible metals, results in an increase in burning intensity and possible explosion.

(2) Water applied to alkali metals not involved in the fire will result in hazardous decomposition, ignition, or explosion.

(3) Application of carbon dioxide on combustible-metal fire adds to the intensity of the burning. Most combustible metals ignite and burn in 100 percent carbon dioxide atmospheres.

(4) Dry chemical extinguishers react with alkali metals and intensify the fire.

(5) Dry chemical extinguishers utilized on nonalkali metal fires are ineffective in controlling the metal fire but might be effective where ignitable (flammable or combustible) liquids are used and the metal is not yet involved in the fire.

(6) Halogenated extinguishing agents used on alkali metals can result in an explosion.

(7) Halogenated extinguishing agents will have a detrimental effect on other combustible metal fires, with the decomposition producing hazardous by-products.

(8) A primary metal fire displays intense orange-to-white flame and can be associated with a heavy or large production of white or gray smoke.

(9) When water is applied to nonalkali combustible metal, it can disassociate to the basic compounds, oxygen and hydrogen. Similar results occur with carbon dioxide.

(10) When water is applied to alkali metals, hydroxides and hydrogen are generated immediately.

(11) Fires involving combustible metals that contain moisture exhibit more intense burning characteristics than dry product.

(12) Extreme heat can be produced. For example, burning titanium and zirconium have the potential to produce temperatures in excess of 7000°F (3857°C) and 8500°F (4690°C), respectively.

(13) Dusts, fines, and powders of combustible metals present an explosion hazard, especially in confined spaces.

(14) Dusts, fines, and powders of titanium and zirconium present extreme hazards; zirconium powders have ignition temperatures as low as 68°F (20°C). Static electric charges can ignite some dusts and powders of titanium and zirconium.

(15) Zirconium and titanium powder can exhibit pyrophoric characteristics.

(16) Turnings and chips of combustible metals can ignite and burn with intensity, especially if coated with a petroleum-based oil, with some spontaneous combustion having been observed.

(17) With the exception of alkali metals, the larger the product, the smaller the likelihood of ignition. Bars, ingots, heavy castings, and thick plates and sheets are virtually impossible to ignite and, in most cases, self-extinguish when the heat source is removed.

(18) The sponge product of most combustible metals burns at a slower rate but still produces tremendous heat.

(19) Burning combustible metals can extract moisture from concrete and similar products that can intensify burning and cause spalling and explosion of the products and spewing of chunks of concrete.

(20) Burning metal destroys asphalt and extracts moisture from rock, which can explode spewing rock fragments.

(21) Most fires involving nonalkali combustible metals usually cannot be extinguished, and unless they are placed in an inert atmosphere of argon or helium, they can only be

controlled.

(22) Fires involving large quantities of metals must cool for at least 24 hours prior to being disturbed to prevent re-ignition.

(23) Fires will oxidize most metals and provide a protective covering limiting open burning.

(24) Alkali metal fires can be extinguished with the suitable extinguishing agents correctly applied.

(25) Combustible metal fines and powders that are stored and contain moisture can produce hydrogen gas.

(26) Combustible metal fines and dusts that are reduced (not oxidized) and that come into contact with other metal oxides can result in thermite reactions.

10.7.5.8

Prior to the arrival of alkali metals on site, the local fire department shall be notified of both the presence of water-reactive materials on site and the hazards of using water on alkali-metal fires.

10.8 Sulfur.

10.8.1 Protection.

Protection for covered liquid sulfur storage tanks, pits, and trenches shall be by one of the following means:

(1) Inert gas system in accordance with NFPA 69

(2) Steam extinguishing system capable of delivering a minimum of 2.5 lb/min (1.13 kg/min) of steam per 100 ft^3 (2.83 m^3) of volume

(3) Rapid sealing of the enclosure to exclude air

10.8.2 Snuffing Steam and Sealing Steam Precautions.

10.8.2.1

The vent systems on enclosed sulfur tanks and sulfur pits shall be designed to allow the required snuffing steam rate or sealing steam rate to vent without overpressuring the enclosure.

10.8.2.2

The vent systems shall also be designed for proper operation during normal operation.

10.8.3 Water Extinguishing Precautions.

10.8.3.1

Liquid sulfur stored in open containers shall be permitted to be extinguished with a fine water spray.

10.8.3.2

Use of high-pressure hose streams shall be avoided.

10.8.3.3

The quantity of water used shall be kept to a minimum.

10.8.4 Dry Chemical Extinguishers.

Where sulfur is being heated by a combustible heat transfer fluid, dry chemical extinguishers complying with NFPA 17 shall be provided.

10.8.5 Nozzles.

It shall be permitted to use straight stream nozzles or combination nozzles to reach fires in locations that are otherwise inaccessible.

10.9 Wood Processing and Woodworking Facilities. (Reserved)

10.10 Combustible Dusts and Particulate Solids Not Otherwise Specified. (Reserved)

Supplemental Information

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Committee: CMD-FUN

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Committee Statement

Committee Statement: The requirements throughout NFPA 660 pertaining to emergency planning and response have been consolidated into Chapter 10. The Technical Committee on Fundamentals of Combustible Dust asks the other Technical Committees to consider removing duplicative requirements from the other chapters.

Response Message: FR-31-NFPA 660-2026

Public Input No. 44-NFPA 660-2025 [Chapter 10]

Public Input No. 175-NFPA 660-2026 [Chapter 10 [Title Only]]

First Revision No. 32-NFPA 660-2026 [Section No. A.3.3.21]

A.3.3.21 Conductive.

A typical threshold for solid materials would be a volume resistivity less than 10^5 ohm-m. The typical test procedures for volume resistivity include ASTM D991, *Standard Test Method for Rubber Property Volume - Resistivity of Electrically Conductive and Antistatic Products*, and ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*. (CMD-FUN)

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 15:35:38 EST 2026

Committee Statement

Committee Statement: The information on Volume Resistivity is from NFPA 77 and provides additional guidance.

Response Message: FR-32-NFPA 660-2026

Public Input No. 126-NFPA 660-2025 [Section No. A.3.3.21]

First Revision No. 16-NFPA 660-2026 [Section No. A.7.3.3.3]

A.7.3.3

Each and every process component should be evaluated, including ducts, conveyors, silos, bunkers, vessels, fans, and other pieces of process equipment. Each point along the process should be described, and hazards at each point should be identified. Remedial measures for each hazard should be identified and documented. The means by which the hazard should be managed is then determined. Usually the relevant industry- or commodity-specific NFPA standard will provide options. The process and process equipment will often determine which option is most appropriate. *(Refer to Annex B for an example of a process hazard analysis.)*

Submitter Information Verification

Committee: CMD-FUN

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Committee Statement

Committee Statement: This material is applicable to multiple paragraphs under 7.3.3.

Response Message: FR-16-NFPA 660-2026

First Revision No. 18-NFPA 660-2026 [Section No. A.7.3.4.2]

A.7.3.4

Each and every facility compartment containing combustible particulate solids should be evaluated. The complete contents of the compartment should be considered, including hidden areas. Each area in the compartment should be described, and hazards at each point should be identified. Remedial measures for each hazard should be identified and documented. The means by which the hazard should be managed is then determined. Usually the relevant industry- or commodity-specific NFPA standard will provide options. *(See Annex ~~C~~ B.5 .)*

The DHA for building compartments should distinguish between localized flash fire hazards and conditions that present a hazard of a propagating deflagration through a suspended dust accumulation throughout a building compartment or portion thereof. The DHA should document where each hazard exists in the building compartment as this information is needed in order to comply with 8.6.1.

Submitter Information Verification

Committee: CMD-FUN

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Committee Statement

Committee Statement: This material is being attached to 7.3.4 rather than 7.3.4.2 because it is applicable to multiple paragraphs under 7.3.4.

The reference to Annex C is being revised because the material is moving to Annex B.

Response Message: FR-18-NFPA 660-2026

First Revision No. 34-NFPA 660-2026 [Section No. A.8.6.2.1]

A.8.6.2.1

A specific evaluation of the work environment to determine the requirement for the wearing of flame-resistant garments should be based on the potential hazards that workers are exposed to as part of their work duties.

Annex V provides an outline of a process for developing a personnel protection strategy and for quantifying the hazard to personnel for determining where flame resistant garments (FRG) are needed and if FRG is sufficient to achieve the personnel protection objectives.

Submitter Information Verification

Committee: CMD-FUN

Submittal Date: Tue Jan 27 17:11:17 EST 2026

Committee Statement

Committee Statement: Annex V has been written to provide extensive guidance for the user on how to quantitatively assess the hazard and means to manage it. This revision provides a reference to this resource.

Response Message: FR-34-NFPA 660-2026

Public Input No. 102-NFPA 660-2025 [Section No. A.8.6.2.1]

First Revision No. 141-NFPA 660-2026 [Section No. A.8.7.2(4)]

A.8.7.2(4)

International guideline BS EN 1127-1, *Explosive atmospheres, explosion prevention and protection — Basic concepts and methodology,* distinguishes the following 13 different types of ignition sources. This ignition source list is well suited to inform DHAs and incident investigations.

(1) Hot surfaces (e.g., heated equipment, friction on shafts and bearings, process equipment, and connecting piping)

(2) Flames and hot gases, including hot particles (e.g., hot work, open flames, fuel fired equipment, and burning embers)

(3) Mechanically generated sparks (e.g., impact- and friction-generated sparks)

(4) Electric apparatus (e.g., “on/off” switches)

(5) Stray electric currents and cathodic corrosion protection (e.g., welding equipment)

(6) Static electricity (e.g., propagating brush, brush, cone discharges, and static shock)

(7) Lightning

(8) Radio frequency (e.g., radio transmissions, welding, cutting, and heating applications)

(9) Electromagnetic waves (e.g., rotating equipment generates fields, light waves, and lasers)

(10) Ionizing radiation (e.g., X-rays and gamma rays)

(11) Ultrasonic (e.g., SONAR, gauging devices, and spray nozzles)

(12) Adiabatic compression and shock waves (e.g., piston action)

(13) Exothermic reactions, including self-ignition of dust (e.g., wet grain decomposition)

~~In addition, FM Property Loss Prevention Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosion and Fire,* provides losses as a function of ignition source. See Table A.8.7.2(4) .~~

~~Table A.8.7.2(4) Losses by Cause (Ignition Source)~~

~~Cause Type~~	~~Number of Losses~~	~~Gross Loss in Millions of Dollars (US)~~
~~Friction~~	~~50~~	~~64.5~~
~~Spark~~	~~38~~	~~24~~
~~Chemical action~~	~~16~~	~~25~~
~~Hot work~~	~~13~~	~~2.7~~
~~Burner flame~~	~~10~~	~~151~~
~~Electricity~~	~~6~~	~~4~~
~~Static electricity~~	~~6~~	~~4~~
~~Overheating~~	~~4~~	~~2.4~~
~~Hot surface~~	~~2~~	~~2~~
~~Unknown/no data~~	~~21~~	~~13.7~~
~~Total~~	~~166~~	~~284~~

~~*Source:* FM Property Loss Prevention Data Sheet 7-76, *Prevention and Mitigation of Combustible Dust Explosion and Fire,* May 2008–2017.~~

Submitter Information Verification

Committee: CMD-FUN

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Committee Statement

Committee Statement: This revision was developed by NFPA staff for editorial purposes, in accordance with 4.3.9.3.2 and 4.3.9.3.3 of the Regulations Governing the Development of NFPA Standards (www.nfpa.org/regs).

FM Data Sheet 7-76 (2024) no longer contains the information from this data table.

Response Message: FR-141-NFPA 660-2026

First Revision No. 25-NFPA 660-2026 [Section No. A.9.4.1.1]

A.9.4

The system information and documentation should include the following:

(1) System design specifications

(2) System installation specifications

(3) Equipment specifications

(4) Operational description

(5) Material combustibility and explosibility information

(6) Fire and explosion protection system specifications and design

(7) System mechanical and electrical drawings

(8) System controls and specifications

The design of these systems should be coordinated with the architectural and structural designs of the areas involved.

Submitter Information Verification

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Committee Statement

Committee Statement: The content of the annex material is broader than the statement of 9.4.1.1. It applies to the overall design and is more appropriately connected to the heading 9.4.

Response Message: FR-25-NFPA 660-2026

First Revision No. 35-NFPA 660-2026 [Chapter V]

Annex V Guide for Computing Thermal Dose to Personnel ~~from Flash Fires and Building Compartment Deflagrations~~ for a Workplace Hazard Assessment (CMD-FUN)

V.1 Introduction.

~~NFPA 660 uses the determination of the existence of a *flash fire hazard* as the trigger for the requirement for the use of flame-resistant garments (FRG) to protect personnel from that hazard. Section 8.6.1.1 states: "Flame-resistant garments designed in accordance with NFPA 2112 shall be permitted to be used as part of the personnel protection strategy against localized flash fire exposures, only." This implies that there can be situations where the protective capabilities of FRG will not be capable of achieving the personnel protection objective. The methodology to evaluate this is critically needed.~~ Relatively brief exposures to even small flash fire events can result in the ignition of ordinary clothing. Once an occupant's clothing ignites, serious and often fatal burn injuries are likely. [1] NFPA 660 uses the determination of the existence of a flash fire hazard from the dust hazards analysis (DHA) as the trigger for the requirement in 8.6.1 for protecting occupants from that hazard.

One option for protection of personnel is to require that those personnel exposed to flash fire hazards from a deflagration wear flame-resistant garments (FRG). NFPA 2112 provides requirements for the design of FRG, and NFPA 2113 provides requirements for the selection and use of such personnel protective garments. NFPA 2113 requires that the facility operator perform a workplace hazard assessment to identify where within the facility the occupants should be equipped with FRG and provides general requirements for the workplace hazard assessment in 4.2.3 . However, NFPA 2113 does not provide a detailed method for identifying where a flash fire hazard exists or explicit quantitative criteria for distinguishing hazardous areas from nonhazardous areas. This annex provides guidance on how to execute a quantitative hazard assessment for facilities covered under the scope of this standard.

Depending upon the fire scenario, the thermal flux (heat flow into the target) can be via radiation, convection, or conduction, or a sum of more than one of the individual modes of heat transfer. Since this annex addresses primarily when FRG should be used and when it should not be considered sufficient, it addresses only the first two heat transfer modes.

The user of this annex should remain mindful that FRG cannot provide adequate protection against all flash fire scenarios. The facility operator should ensure that FRG is not relied upon as a safeguard for scenarios where the intensity and/or duration of a flash fire can exceed the protective capabilities of the FRG.

V.2 Workplace Hazard Assessment for Facilities within the Scope of NFPA 660.

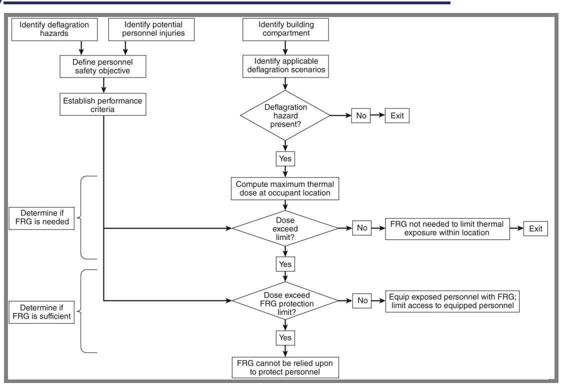
The DHA should identify building compartments and areas where flash fire hazards exist. However, the DHA might apply the hazardous designation to an entire compartment or area when the hazard actually exists only in a fraction of a building compartment or exposes only a fraction of the employees in the compartment. Consequently, the facility operator must have a means of establishing a dividing line between those areas where the hazard exceeds the facility fire safety objectives and where it does not. Furthermore, simply equipping all personnel with NFPA 2112/2113 FRG does NOT guarantee personnel safety. If the thermal output of a flash fire at a given location exceeds the total thermal dose limiting capability of the garment, the injury to the personnel will exceed the tolerable limit.

The workplace hazard assessment process starts with the identification of the personnel safety objectives for the facility. Once the objectives are established, explicit performance criteria usually expressed as a radiant flux intensity (kW/m^2) or thermal dose (kJ/m^2) are derived from them. The performance criteria are used to determine where in the building compartment the potential thermal dose from a flash fire scenario is expected to result in personnel injury that exceeds the tolerable personnel injury for the facility. Once explicit personnel injury limits are established, each hazard area is evaluated to determine where in each area the thermal dose exceeds the personnel injury limits. Personnel occupying portions of the hazard area where the thermal dose exceeds the personnel injury limit must be protected or prevented from occupying that location. One means of protection for personnel under some, but not all, circumstances is equipping them with FRG.

However, the process does not stop with that determination. If FRG is to be relied upon, the protective capabilities of the FRG must be sufficient to prevent injury. If the thermal performance of the FRG exceeds the thermal dose at a given occupant location, FRG can be used to achieve the safety objectives. If the thermal dose exceeds the protective capabilities of the FRG, that hazard area should not be occupied during time periods when the hazard exists.

This analytical process reflected in this annex is summarized in Figure V.2 .

Figure V.2 The Analytical Process Reflected in Annex V.



V.2.1 Hazard Management Strategy Development.

The hazard management strategy development is started by establishing clear objectives for personnel safety. Once a personnel safety objective has been established, a qualitative or quantitative personnel protection criterion can be derived. This criterion will be used to determine if a protection strategy achieves the objective under a given fire or deflagration scenario. Fire and deflagration scenarios are then developed to determine if a strategy achieves the objectives. Deflagration scenarios are generally divided into inherently limited deflagrations in which the size of the deflagration flame is limited by the availability of fuel or some other limiting factor, and “building compartment deflagrations” (BCDs) in which the flame extension is limited only by the building compartment enclosure. BCDs usually are due to the effectively unlimited availability of fuel from accumulated fugitive dust. In each case, radiant intensities on or thermal doses for employee(s) under credible worst-case circumstances are computed. These radiant intensities and thermal doses are compared to the performance criteria associated with the personnel safety criteria to verify that the personnel protection objectives will be achieved.

V.2.2 Personnel Safety Objective.

The first step in designing a personnel safety system is to define the maximum level of personnel injury that the facility is willing to tolerate. This establishes a personnel safety objective, usually in the form of a concrete objective statement like “No personnel shall sustain a permanent life-altering injury or suffer fatality.”

It is not within the scope of NFPA 660 to establish injury prevention objectives for facilities covered by the scope of the standard. The facility owner/operator should do this. The owner/operator should understand that the design of personnel protection strategies begins with establishing injury prevention objectives. Once objectives are established, concrete performance criteria can be developed that will serve as the basis for measuring whether a personnel protection strategy can or will achieve the objective.

V.2.3 Personnel Safety Performance Criteria.

The personnel safety objective is used to establish performance criteria. These can be either qualitative or quantitative. A qualitative criterion might be the prevention of melting or ignition of occupant's clothing, which is likely to result in serious burn injuries or fatality. A quantitative criterion might be the thermal dose (kJ/m^2) necessary to produce the threshold injury to personnel established in the objective policy statement.

To evaluate the qualitative criterion of preventing ignition of clothing, the properties of the clothing are important. The ignition temperature for clothing varies considerably depending upon the type of fiber, weight of the finished cloth, age, and so forth. The ignition of ordinary clothing made of cotton and polyester fabrics has been reported when it is exposed to relatively short-duration radiant flux on the order of 50 kW/m^2 in some references, while other references report ignition at attained temperatures of 200°C to 300°C. [2,3] It is also conceivable that a facility operator would elect to have the melting and ignition characteristics of a specific type/brand of employee uniform tested to obtain data characterizing its performance criteria.

When the scenario involves an inherently limited deflagration and direct flame impingement or engulfment is not contemplated, thermal exposure to the occupant is strictly radiant, and separation distance is one method that can be used to limit probability of injury. The radiant flux intensity and thermal dose criteria often used for personnel injury thresholds to bare skin are as follows: [4,5]

Bright sunlight	1.37 kW/m^2
Pain threshold	41.9 kJ/m^2
Blister, severe second-degree burn	83.8 kJ/m^2
Severe third-degree burn	162.5 kJ/m^2

Note: Thermal dose (kJ/m^2) is radiant flux intensity (kW/m^2) multiplied by exposure time (seconds).

When the qualitative objective is similar to the "no permanent life-changing injury" objective, only the top two criteria are applicable. The severe second-degree burn criterion can be used. A thermal dose that leads to severe third-degree burn injury exceeds the level of injury implied by the objective and should be considered a fatal injury threshold.

In some cases, a facility operator might elect to use a more qualitative criterion. A qualitative criterion might be the prevention of ignition of occupant's clothing. Since ignition of clothing results in enormous and immediate thermal flux increase to the person, the objective of preventing serious permanently injurious burns ceases to be achievable and fatality becomes likely. The ignition temperature referenced in the previous paragraphs can be used.

In the case of burn injury hazard management, different personnel injury criteria will be applicable depending on the deflagration scenario. The chemical composition of the fuel and suspended particulate in the radiant flux transmission path, as well as the separation distance between the deflagration flame surface and the target occupant, all affect the radiant flux intensity impinging on the target occupant. These parameters should be stipulated in the deflagration scenario.

To evaluate the radiant and convective heat transfer potential, fire scenarios are developed that provide either the radiant flux or convective thermal flux that represents the design fire against which the fire protection strategy for the employees is evaluated.

V.2.4 Performance Criteria Selection.

The facility operator should establish as a policy the level of injury deemed tolerable versus intolerable in qualitative terms. That qualitative criterion can then be translated into a quantitative criterion suitable for engineering calculations.

For example, an operator could adopt a policy that no employee suffer pain lasting longer than 10 seconds as a consequence of a dust deflagration in the facility. Research has been reported that below a radiant flux of 1.7 kW/m^2 no subject reported pain regardless of exposure duration. [6,7] Consequently, a radiant flux intensity of 1.7 kW/m^2 could be used as a quantitative criterion for this employee impact objective. It could be used to establish a lower threshold, beneath which no exposure limitation is needed.

A relation has been developed to predict the occurrence of second-degree burns (skin blister formation). [8] The data suggest that the difference in radiant flux leading to the onset of blisters and severe blistering is small. Data for the onset of third-degree burn injury was not available. Consequently, if the design objective is to prevent life-altering injury implied by the onset of third-degree burns, the following relation for second-degree burns can be used as a bounding-value estimate for the onset of third-degree burn injury criterion:

$$t_B = 200\left(\frac{\dot{q}''}{1000}\right)^{-1.46} \quad \text{[V.2.4]}$$

where:

t_B = time to skin blister (sec)

$\dot{q}''$ = incident thermal radiant flux intensity (W/m^2)

This relation includes a 50 percent safety margin, and its use with this safety margin is recommended to compute the time at which skin blistering has occurred when exposed to the radiant flux, $\dot{q}''$. [9]

Alternatively, an operator could adopt a policy that no employee suffers a permanent life-changing injury to more than 10 percent of their body as a consequence of a dust deflagration. This objective would tolerate burns to parts of the head, face, or hands but would preclude the ignition of the occupant's clothing. In this case the radiant flux used to predict the ignition of clothing, usually on the order of 50 kW/m^2 or attained temperatures of 200°C to 300°C, depending on the experimental conditions, could be used for the performance criterion.

For those locations where the deflagration flame volume is inherently limited by either the availability of fuel, the extent of the particulate suspension, or the availability of oxidant (rarely the case in occupied building compartments), a minimum separation distance between the nearest occupant and the deflagration flame can be computed using the relations in V.3.2 to determine the separation distance needed to achieve the performance objective. However, if there is entrainable, accumulated fugitive dust in the building compartment, the deflagration flame volume ceases to be inherently limited and a BCD is a likely result (see V.3.1). In this case, separation cannot be relied upon to manage the hazard to personnel.

For those cases where the flash fire flame is expected to impinge on one or more occupants, a strategy for protecting those employees from the ignition of their clothing is critical. Usually, facility operators resort to equipping those employees in FRG. However, when this strategy is adopted, it is critical to verify that the FRG used will provide the level of protection needed. This also makes it necessary to quantify the circumstances where flame impingement is expected. Since the thermal protective capabilities of NFPA 2112/2113 FRG is finite, the use of NFPA 2112 FRG cannot guarantee that the wearer will not suffer bodily burn injury from a flame impingement or burns to the throat and lungs from flame engulfment from a dust deflagration.

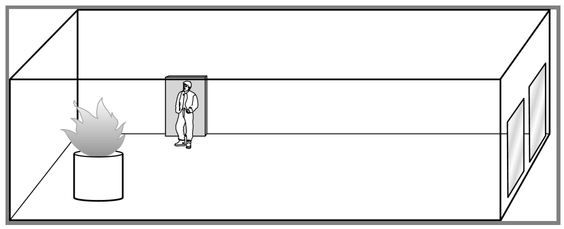
V.3 Hazard Area Analysis.

V.3.1 Fire and Deflagration Scenarios.

The next step is to identify scenarios that would expose employees to a thermal hazard. Since the scope of NFPA 660 encompasses facilities handling combustible dusts, the scenarios would be derived from the DHA, focused on the thermal exposure of employees to flash fires involving a deflagration of suspended dust or dust/solvent mixture.

The flash fire exposure scenarios for facilities covered by NFPA 660 fall into two categories. The first is a flash fire resulting from the ignition of a dust suspension of inherently limited size. An example of this would be the ignition of a dust/air suspension or ignitible liquid vapor forced out of the ullage volume of a mixer during the addition of a combustible resin. This scenario is illustrated conceptually in Figure V.3.1(a) .

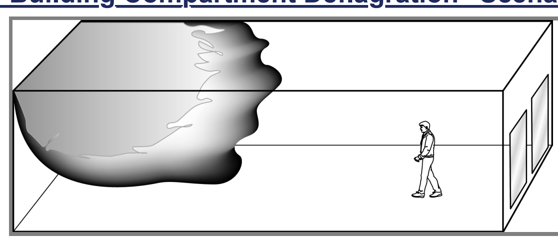
Figure V.3.1(a) The Inherently Limited Deflagration Scenario.



As long as there is no accumulated fugitive dust in the building compartment that can be dislodged, suspended, entrained, and ignited by the initial deflagration, the flash fire is inherently limited by the quantity of fuel ejected from the mixer and the volume of the suspension or mixture. The distance between the source of radiant flux and the occupant is limited to the volumetric expansion of the deflagration flame. When considering this scenario, the analyst should consider the potential for the ejection of additional fuel (dust) out of the process vessel by the force of the deflagration that can expand the deflagration flame volume as the ejected dust mixes with fresh air and burns.

The second scenario is where an initial deflagration occurs in a building compartment where there exists a combustible dust suspension or where fugitive combustible dust has accumulated on interior building compartment surfaces. In this scenario, the accumulated dust load is often dislodged and dispersed by the pressure pulse from the initial event. The flame of the initial deflagration ignites the suspended dust, resulting in a deflagration flame front propagating across the interior volume of the building compartment. This scenario, a BCD, is illustrated conceptually in Figure V.3.1(b) .

Figure V.3.1(b) The “Building Compartment Deflagration” Scenario.



As the deflagration flame front propagates through the dust suspension within the building compartment interior, the expanding combustion product gases behind it force both the flame and the suspended, unburned dust cloud across the interior volume of the building compartment. In this case, the source of radiant flux is moving towards the occupant, rapidly increasing the radiant flux intensity impinging on the occupant. Furthermore, since the flame front has a supply of fuel, the requisite conditions to continue the combustion spread across the compartment interior. The burning cloud should be expected to impinge on any occupants in the building compartment

V.3.2 Estimating Radiant Flux Hazard.

There are a number of computational methods for estimating the radiant flux impinging on a target as a function of a given fire geometry. [10] The suitability of a computational method for a given fire/deflagration scenario depends on the fire/deflagration scenario and the performance objectives for the facility design.

Since the radiant flux from a deflagration is determined by the size of the dust suspension, the fuel, and the dust concentration, any deflagration scenario begins with the stipulation of these quantities as a source definition. For the inherently limited deflagration scenario this usually entails the assumption that the entire interior of an enclosure is occupied by a dust cloud at the worst-case concentration, c_w . For the BCD scenario, while the deflagration might begin with a localized deflagration flame, the existence of a dust cloud in the building compartment provides the fuel needed to extend the deflagration flame across the compartment interior. This allows the radiating area of the flame to expand to the full cross-sectional area of the building compartment as well as travel towards the target occupant. Both of these result in a significant increase in the predicted impact on personnel.

In this annex, the calculations yield a computed radiant flux intensity measured in kW/m^2 . Injury is the consequence of a thermal dose measured in kJ/m^2 . Since the reaction of personnel to a deflagration incident is rarely predictable, exposure time is impossible to accurately quantify. Consequently, the radiant intensities calculated are compared to performance criterion radiant intensities rather than doses associated with personnel safety objectives.

V.3.2.1 Inherently Limited Deflagration of Particulates (Dusts).

There are two mathematical relations in common use for estimating the radiant emissions from a fire. The first is based upon the heat release rate of a point source. The second is based upon the flame temperature of point source. The user of this annex should select the relation used to estimate the radiant flux of the deflagration based upon on the available data regarding the fuel involved. Each relation is subject to its own uncertainties, limitations, and underlying assumptions.

The relation based upon the heat release rate of the point source radiator has been validated for hydrocarbon liquid fires. The flames are diffusion rather than premixed flames. The relation can be applied to nonmetallic dusts based upon the presumption that ordinary (nonmetallic) fuels pyrolyze upon heating, yielding pyrolyzate vapors that burn like hydrocarbon liquids. It assumes that the customarily used radiative fraction for such fires is appropriate. Additionally, the error from approximating a definite area as a point becomes large as the separation distance becomes smaller compared to the area. This relation is not applicable to metallic dusts.

The relation based upon flame temperature of a point source is based on the presumption that dust deflagration flames emit radiation that can be quantified using Planck's Law and a Stefan-Boltzmann correction for gray body emissivity. But flames, especially those of burning vapors and gases, are not solid masses but are a mixture of gaseous oxidized fuel molecules that should not be modelled as a black body or gray body radiator. Only the oxides resulting from the combustion of metallic particulates are solid metal oxide particles, and a gray body radiator approximation can be applicable to these fuels. But the user should keep in mind that flame temperature measurements are dependent on the combustion conditions and measuring method. If the temperature is inferred from pressure data for a stoichiometric concentration, it might not accurately predict the flame temperatures of an accidental uncontrolled deflagration.

Consequently, both relations presented in this annex are inherently imprecise due to uncertainties in input parameters. The user is urged to perform a sensitivity analysis on all calculations.

V.3.2.1.1 Heat Release Rate of a Discrete Point Source Relation.

To estimate the radiant emission from an inherently limited deflagration (flash fire) of a nonmetallic particulate, a point source approximation for a discrete fireball can be used. This approximation is developed from an estimate of the heat release from the deflagration and a calculated radiant flux intensity impinging upon the contemplated target individual, as shown in Figure V.3.2.1.1 . For combustible dust processing facilities, the heat release estimate is usually derived from the maximum anticipated dust suspension cloud volume at the worst-case concentration, c_w , the concentration at which P_{max} was attained during testing. Clearly, the dust suspension cloud volume estimate is dependent on the facility and its particular process equipment. It is critical to limit the use of this calculation to only those facilities where there are no suspendable or entrainable dust accumulations adjacent to the dust suspension cloud that could extend the combustion zone beyond the volume considered in the scenario.

One computational model that is applicable to the inherently limited deflagration is the point source/inverse square law model. This computational model is widely used. It is used for the design of fire detection systems using radiant-energy-sensing fire detectors in NFPA 72 . [11]

Even though an actual fire has height and width, the energy release from the fire is treated by NFPA 72 as a quantum radiator emitting radiant energy from a point on the center of the front (nearest) surface of the optically dense flame. The radiant flux intensity (radiant power per unit area) at the detector (the target) is computed based upon the sensitivity of the detector that is derived from the product listing investigation, the radiant flux intensity of the source, and the inverse square law.

Drysdale models the radiant power from an ignitible liquid pool fire as a Planckian radiator emitting with a radiative fraction, X . [12]

The application of this relation to predicting radiant flux from a deflagration (flash fire) is addressed by Beyler in the SFPE *Handbook of Fire Protection Engineering* , Chapter 66. For a hypothetical point source radiator the incident radiant flux, q , impinging on a target a specified distance from the deflagration center can be predicted using the relation in Equation V.3.2.1.1. [13]

$$q = \tau X_r \left(Q / 4\pi L^2 \right) \cos\Theta \qquad \textbf{[V.3.2.1.1]}$$

where:

q = received radiant flux (kW/m^2)

τ = atmospheric transmittance (unitless)

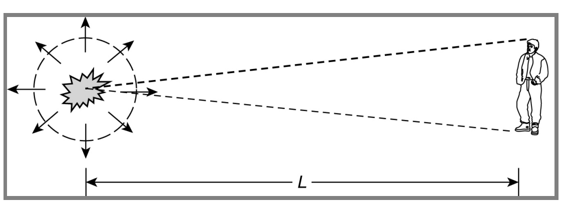
X_r = radiative fraction of the heat release (fractional value)

Q = heat release rate (kW)

L = distance from center of fire ball to target (m)

Θ = angle of hypothetical target plane to flame exposure path

Figure V.3.2.1.1 The Point Source Model for Radiant Emission from a Deflagration to a Target Occupant.



Since the target in this annex is a human that has roughly the same exposed surface regardless of what direction the person was facing, the angle between the target plane and the radiant flux vector is always 90 degrees. This makes cos Θ = 1. Secondly, we assume a worst-case circumstance with no atmospheric absorbance in the transmission path, meaning transmittance is 100 percent, making τ = 1. Correlations have been developed for radiative fraction based upon vapor pressure for gaseous releases, but none exist for clouds of combustible dusts. [14]

To use this relation, one must have a value for the heat release rate of the deflagration. This can be computed from the total heat release divided by the deflagration flame duration. For deflagration flames that run their course in 1 second, a bounding value estimate for the radiant flux intensity from a dust deflagration can be obtained by computing the mass of dust suspended in the dust suspension cloud, assuming worst-case concentration, c_w, the net heat of combustion of the fuel, ΔH_c, and a numerical value for radiative fraction, X_r.

The radiative fraction, X_r, is reported to have values from 0.1 to 0.4. [15] Customarily, fire protection engineers use a radiative fraction, X_r, of 0.3 to 0.35 for diffusion flames. This value for X_r has been derived from research primarily focused on hydrocarbon pool fires and for flammable gas and vapor cloud fires. There is very limited research investigating a radiative fraction for deflagration flames involving combustible dusts. Where commonly encountered particulates like agricultural, forest, animal-derived, and plastic products are concerned, the fuel particulate must first pyrolyze into ignitible vapors, chemically similar to ignitible liquid fuels, before burning. Consequently, it is unlikely that the use of this value for X_r for those dusts introduces an unacceptable error. However, this has not been explicitly validated yet. The value for Q is a function of the total heat released in the fireball and the duration of the fireball. See V.3.2.1.4 for calculation details.

The point source/inverse square law model becomes increasingly less reliable as the distance between the deflagration flame and the occupant decreases. The point source approximation is applicable only in scenarios where the separation distance (L) is much greater than the diameter (D) of the fireball. At closer distances, the point source method has been shown to under-predict heat fluxes to a target. As a general guideline, the point source model should not be applied where the estimated heat fluxes at the target are below 5 kW/m^2. [16]

V.3.2.1.2 The Spherical Fireball Model.

An alternative method to obtain a radiant flux estimate is to compute the circular radiating area of the optically dense spherical suspension and apply an average surface emissivity and geometrical configuration factor between the fireball and target.

Flames are optically dense (also called optically thick) radiators. This allows one to base the calculations on the radiating area of the flame and an average emissive power per unit of area rather than on the actual flame volume. Furthermore, the radiating area consists only of that portion of the surface of the flame that has a direct transmission path to the target. This allows us to model a spherical deflagration as a circular radiating area of the same diameter as the spherical flame with an average emissive power per unit area.

An average emissive power per unit area of 350 kW/m^2 is widely used for ignitible liquid and flammable gas deflagrations. [17] The value of 200 kW/m^2 to 350 kW/m^2 has been suggested for the average emissive power for BLEVE deflagrations. [18] It is important to keep in mind that when an average emissive power per unit of deflagration flame area is used, one should not apply the radiant fraction, X_r, correction because the numerical value for the average emissive power is the measured radiant power from a fire of known total heat release rate. With the above in mind, Equation V.3.2.1.2a can be used to compute an estimate of the radiant flux intensity impinging upon a target (occupant) at a known separation distance from a deflagration of known HRR.

When using an average emissive power, E, (kW/m^2) to model the deflagration, it is generally expressed as shown in Equation V.3.2.1.2. [19]

$$q = \tau E F \qquad \textbf{[V.3.2.1.2a]}$$

where:

q = incident radiant power intensity (kW/m^2)

τ = transmissivity of medium, air (percent)

E = average surface emissive power intensity (kW/m^2)

F = geometric configuration factor

Assigning the value of 1 to τ for clear air and surface emissive power intensity of 350 kW/m^2 for hydrocarbon fuels is shown in Equation V.3.2.1.2b.

$$q = 350F \qquad \textbf{[V.3.2.1.2b]}$$

Since the parameter E has units of kW/m^2 it is an intensity, and the total emissive power (kW) is found by multiplying the surface emissive power intensity by the radiating area of the deflagration flame.

The configuration factor is calculated as a function of the expected fireball dimensions and separation distance to a target using the method presented by Beyler. [20]

$$F = \left(r^2 / L^2\right)\cos\Theta \qquad \textbf{[V.3.2.1.2c]}$$

where:

r = radiator radius, ½ radiator diameter

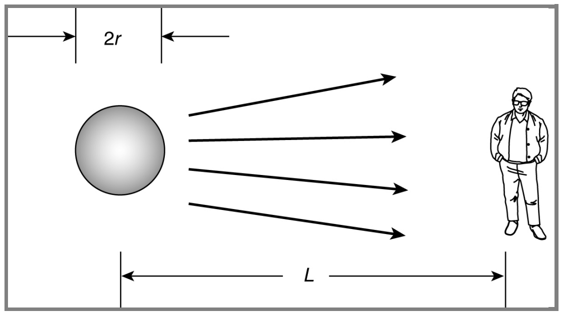
L = separation distance from center of flame to target

Θ = angle of incidence to front surface of target

This method presumes that the radiant flux from a spherical deflagration flame is impinging on a flat absorptive surface that is not necessarily at right angles to the line from the center of the radiator to the center of the target. This is NOT the case when considering the potential for personnel injury. It does not matter what side of a person's body is burned or which side of their clothing ignites. In the case of personnel radiant impingement, the angle of incidence, Θ, is always 90 degrees and the cos Θ is 1. For this case, Equation V.3.2.1.2c reduces to that shown in Equation V.3.2.1.2d. [21]

$$F = r^2 / L^2 \qquad \textbf{[V.3.2.1.2d]}$$

Figure V.3.2.1.2 The Parameters in the Configuration Factor for Heat Release Rate of the Spherical Fireball Model Relation.



V.3.2.1.3 Flame Temperature of a Spherical Fireball Relation.

As an alternative to the assumed average surface emissive power value of 350 kW/m^2, the radiant thermal flux from a flame can also be calculated from the flame temperature and the radiating area as a Planck's Law radiator. This relation does not rely on the use of experimental radiant flux data obtained from ignitible hydrocarbon gases and liquids, making it useable for both the ordinary combustible particulates as well as the combustible metals. Metallic particulates burn with sufficiently different chemistries yielding very different combustion products and often with far greater heat release per unit of fuel mass.

When metallic or other particulates that cannot be approximated with hydrocarbon liquid equivalence are involved, the following relation should be used as the computational model. Rather than starting with a value for heat release rate, Equation V.3.2.1.3 is rewritten based upon the flame temperature, the Stefan-Boltzmann relation for gray body radiators and combined with the inverse square law portion of the point source relation of Equation V.3.2.1.1. The combined relation is shown in Equation V.3.2.1.3.

$$q = \tau\varepsilon\sigma\left(T_f{}^4 - Ta^4\right)r^2/L^2 \quad \textbf{[V.3.2.1.3]}$$

where:

- q = received radiant flux (kW/m^2)
- τ = atmospheric transmittance (unitless)
- ε = Stefan-Boltzmann emissivity of radiator (fractional value)
- σ = Stefan-Boltzmann constant, 5.67×10^{-11} kW/m^2 K^4
- T_f = Flame temperature (K)
- T_a = Ambient temperature (K)
- r = Radius of deflagration flame
- L = Distance from center of fire ball to target (m)

This relation requires a numerical value for the Stefan-Boltzmann emissivity, ε, of the deflagration flame. This factor serves a similar purpose as the radiative fraction, X_r, in equation V.3.2.1.1. It should be experimentally obtained but is often assigned a value of 0.8. A bounding value of 1.0 can be used to obtain a conservative result. [22] The actual emissivity of a deflagration flame is the sum of the quantum emissions resulting from the chemical reactions in the flame and the gray body emissions from the heat content of the combustion products. The gray body fraction can be derived from the sum of emissivity of the each of the combustion products multiplied by their fraction of the total combustion product mass. Keep in mind that the combustion products of a metal dust deflagration are the metal oxides resulting from the combustion reactions that are usually solid particulates.

Flame temperature must be obtained from relevant research. The flame temperatures for diffusion flames involving hydrocarbon fuels are generally on the order of 1,400 K to 1,600 K (1,100°C to 1,900°C). [23] Combustible metal particulates burn at much higher temperatures. The flame temperatures for combustible metal particulates in air suspension are shown in Table V.3.2.1.3 .

Table V.3.2.1.3 Flame Temperatures and Net Heat of Combustion for Combustible Metal Particulates

Element	**Flame Temperature, K [24]**	**Heat of Combustion, MJ/kg [25]**
Aluminum	2800–4000	31.06
Boron	1700	58.83
Carbon	1700–2600	
Chromium	1850–3170	10.78
Hafnium	2400–4850	
Magnesium	2850–3600	24.73
Molybdenum	2600	

Element	Flame Temperature, K [24]	Heat of Combustion, MJ/kg [25]
Nickel	2400	_
Niobium	2100–3540	_
Tantalum	2350–3750	_
Tin	1550–2250	_
Titanium	2850–3990	19.6
Tungsten	1550–3100	4.59
Zinc	1750–2070	5.37

The data for metal dust deflagration flame temperature were not directly measured but rather were computed from pressure data obtained using the USBOM 20-L hemispherical test apparatus. The data for heat of combustion were derived from oxygen consumption cone calorimetry. Published data for other metallic particulate deflagrations has not been found.

Zalosh provides relations for flame radiation based on flame temperature that are similar to the relations given in the previous paragraphs. [26]

V.3.2.1.4 Using the Relations for an Inherently Limited Deflagration.

These relations are suitable for a scenario similar to that in Figure V.3.1(a) where the deflagration is inherently limited and is not constrained by building compartment floor, ceiling, or walls.

Since the scenario presumes an inherent limitation in the diameter or volume of the deflagration, the first step is to establish the maximum, credible worst-case size of the deflagration. This provides the starting point for the calculations that can be used to determine if separation distance can be used as a hazard management method. The scenario is determined by the process environment and the particulate involved. Usually, the scenario is the ignition of the dust/air mixture in the ullage volume of process vessel or the release of a mass of dust into the interior of a building compartment.

Generally, the maximum dust suspension volume at the worst-case concentration, c_w, is assumed to be present and ignited. But this is NOT a bounding-value assumption. Dust concentrations above c_w will still support a deflagration flame front and eject incompletely burned fuel ahead of the flame. As the unburned and partially burned fuel mixes with fresh air it extends the flame front. The deflagration size criterion used for the calculations should address this potential. This is usually done by increasing the volume of the fuel cloud before ignition to evaluate the impact of fuel concentrations above c_w.

Also, it is critical to ascertain that the dust release is truly limited. The potential for the involvement of additional dust should be considered and added to the computed dust cloud fuel load if there is a reasonable likelihood of additional fuel entering into the deflagration scenario such as the ejection of settled dust out from a vessel. If there is the potential for entrainment of previously settled dust on upward-facing accumulation surfaces exterior to the process vessel under consideration, the scenario should be treated as a building compartment deflagration scenario as in V.3.2.2 .

Once the design scenario dust suspension has been determined, the radiant power from the deflagration is determined. Radiant power is computed from the total heat of combustion and the flame duration. The duration of the flame is derived from the flame speed and the diameter of the dust suspension. The speed of the flame front through the dust suspension is the fundamental burning velocity, S_u. A relation has been cited that can be used to derive an estimate of the fundamental burning velocity, S_u. [27]

$$S_u = K_{st} / 4.84\left[\left(P_{max}/P_0\right)-1\right]P_{max} \quad \textbf{[V.3.2.1.4a]}$$

where:

S_u = fundamental burning velocity (m/sec)

K_{St} = measured deflagration index obtained per ASTM E 1226 (bar-m/sec)

P_{max} = maximum deflagration pressure (bar)

P_0 = initial pressure (bar)

This relation can be used to estimate the burning velocity, S_u. The deflagration flame duration can then be estimated using Equation V.3.2.1.4b.

$$t_f = D/S_u \quad \textbf{[V.3.2.1.4b]}$$

where:

t_f = flame duration time (sec)

S_u = fundamental burning velocity (m/sec)

D = dust suspension cloud diameter (m)

Once the deflagration flame duration, t_f, is known, the radiant power of the deflagration flame can be computed.

$$Q = \rho V\left(\Delta H_c\right)/t_f \quad \textbf{[V.3.2.1.4c]}$$

where:

Q = radiant power (kW)

ρ = dust concentration in cloud (kg/m^3)

V = dust cloud volume (m^3)

t_f = flame duration time (sec)

ΔH_c = net heat of combustion of fuel (kJ/kg)

For example, a process is handling a wood particulate with K_{St} = 100 bar-m/sec and P_{max} = 8.0 bar-abs. The ΔH_c = 20 MJ/kg. The worst-case concentration is c_W = 400 g/m^3. The deflagration scenario is a 2.0 m diameter spherical dust cloud.

From Equation V.3.2.1.4a, S_u = 0.55 m/sec. From Equation V.3.2.1.4b, the 2.0 m diameter dust suspension will yield a flame time, t_f = 1.1 sec. The 2.0 m diameter dust suspension has a volume of 4.18 m^3. Using Equation V.3.2.1.4c, we estimate the total radiant power of 30,400 kW. The radiating area of the deflagration is 3.14 m^2 and $1/6$ of the radiant flux is radiated toward the target. This yields a radiant flux intensity of approximately 1613 kW/m^2. This value is larger than the 350kW/m^2 used in equation V.3.2.1.2b. Remember that the 350 kW/m^2 value is experimentally obtained from a diffusion flame, while the calculated value here is from a hypothetical premixed flame at worst-case concentration.

Equation V.3.2.1.1 can be used to calculate the received radiant flux intensity, q, in kW/m^2 as a function of separation distance, L, in meters for a deflagration flame of given volume. Since both the cos Θ and τ terms are equal to 1, Equation V.3.2.1.1 can be reorganized to be explicit in L to obtain the distance at which the received radiant flux intensity is equal to a specified value under a scenario of a given deflagration radiating area and heat release rate of Q, as shown in Equation V.3.2.1.4d.

$$L = \left(X_r Q / 4\pi q\right)^{1/2} \quad \text{[V.3.2.1.4d]}$$

When using equations V.3.2.1.2b and V.3.2.1.2c, reorganizing for a form explicit in L yields Equation V.3.2.1.4e.

$$L = (350 r^2 / q)^{1/2} \quad \text{[V.3.2.1.4e]}$$

These relations can be used to compute the minimum separation distance between the deflagration and the occupant needed to limit the radiant flux intensity to a given level based upon the size and heat release rate of the deflagration.

Similarly, when using the point source flame temperature calculation and setting τ = 1, Equation V.3.2.1.3. can be reorganized to be explicit in L, the separation distance at which the received radiant flux intensity is equal to a specified value under a scenario of a given deflagration flame temperature, T_f, as shown in Equation V.3.2.1.4f.

$$L = \left[r^2 \varepsilon \sigma (T_f^4 - T_a^4) / q \right]^{1/2} \quad \text{[V.3.2.1.4f]}$$

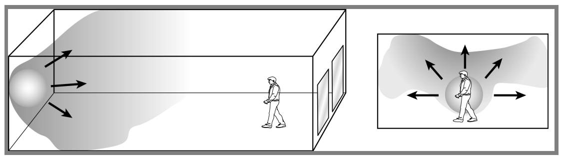
This relation can be used to compute the minimum separation distance between the deflagration and the occupant needed to limit the radiant flux intensity to a given level based upon the size and flame temperature of the deflagration.

V.3.2.2 Building Compartment Deflagration of Particulates (Dusts).

When the radiator is a BCD flame front, the radiant flux intensity at a target occupant cannot be estimated from a simple point source inverse square relation. In the BCD scenario we presume that the deflagration begins either in a pre-existing dust cloud with a concentration sufficient to propagate the deflagration flame front occupying a large fraction of the compartment interior volume, or in a compartment with pre-existing dust accumulations that can become dispersed into the interior volume as a result of the initiating event.

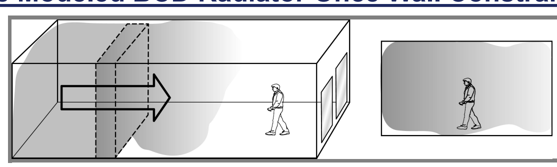
Once ignition occurs, the deflagration propagates radially as a spherical flame front. The radiant source both expands in area and advances across the compartment interior, presumably towards the target. Consequently, the method of calculating the radiant exposure at the target occupant should address the dynamic behavior of the propagating BCD. This is customarily done with a series of successive calculations iterated for short intervals of time as the flame front propagates towards the target occupant. For a deflagration ignited at the edge of a dust suspension at the end of a building compartment, one can envision the initial phase of the event as in Figure V.3.2.2(a) .

Figure V.3.2.2(a) Initial Phase of a BCD, Side View and End View.



When considering the BCD scenarios there are three factors that must be added to the calculations. The first is that the interior building volume between the deflagration flame and the target occupant is NOT totally transmittent, as was assumed in the case of the inherently limited deflagration in V.3.2.1 . Second, the radiating area of the deflagration is NOT a defined size, it is increasing in area until constrained by the building structure, as shown in Figure V.3.2.2(b) . Third, the deflagration flame front is advancing across the compartment interior. The latter two factors are both functions of time. These factors are considered below in that order.

Figure V.3.2.2(b) The Modeled BCD Radiator Once Wall Constraint Occurs.



When there is a dust suspension in the compartment interior, Equations V.3.2.1.1, V.3.2.1.3, V.3.2.1.4a, V.3.2.1.4b, and V.3.2.1.4c must be modified by adding a Beer-Lambert Law absorbance term to address the absorbance of radiant energy due to the pre-existing dust suspension.

Beer-Lambert Law optical absorbance is usually computed with Equation V.3.2.2a. [28, 29]

$$I = I_0 e^{-\mu L} \qquad \textbf{[V.3.2.2a]}$$

where:

I = received radiant flux intensity, kW/m ^{2}

I_0 = initial radiant flux intensity, kW/m ^{2}

e = Naperian logarithm base

μ = atmospheric absorbance coefficient, m $^{-1}$

L = distance, m

Using the variable q'' to designate the reduced radiant flux intensity at the target surface as a result of the absorbance, Equation V.3.2.1.1 is modified with the addition of the Beer-Lambert Law absorbance by the transmission medium to obtain Equation V.3.2.1.4f.

$$q'' = e^{-\mu L} X_r Q / 4\pi L^2 \cos\theta \qquad \textbf{[V.3.2.2b]}$$

where the parameters are defined as in Equation V.3.2.2a. Similarly, Equation V.3.2.1.3

becomes Equation V.3.2.2c.

$$q'' = e^{-\mu L}\varepsilon\sigma(T_f^{\,4} - T_a^{\,4})r^2/L^2$$ [V.3.2.2c]

To use these relations, the absorbance coefficient, μ, of the dust suspension must be quantified. Unfortunately, no research has been found providing numerical values for μ for combustible dusts as a function of concentration. The atmospheric absorbance of a concentration of coal dust at the minimum explosible concentration (MEC) is often cited as being totally obscuring over a distance of 3 m. [30] The phrase totally light obscuring is not sufficiently precise for engineering. An obscuration of 90 percent (10 percent transmittance) leads to an absorbance coefficient, μ, of 0.77. However, optical obscuration is the result of both the absorbance as well as the reflection of radiant energy. Consequently, white or light-colored particulates also produce obscuration.

For most commonly encountered combustible dust powders one would expect a smaller absorbance coefficient than that computed for coal dust. Using a coefficient of 0 means there is no light obscuration, either by absorption or reflection by the particulate, and resulting in no attenuation of the radiant flux intensity by the atmosphere between the deflagration and the occupant in the calculation. This maximizes the computed received radiant flux intensity at the occupant and is a bounding value. Once the particulate is known, a numerical value for μ should be determined by testing.

Equations V.3.2.1.4e and V.3.2.1.4f allow the computation of the radiant flux intensity impinging on a target occupant at a given distance from the flame surface during the initial phase of the BCD development, before wall, ceiling, or floor constraint.

Once constraint begins, the user should model the deflagration flame as a flattened surface advancing towards the occupant. Since the BCD flame has an extended fuel supply ahead of it that allows the flame front to expand, the process of estimating the radiant flux on a target occupant requires computing the radiating area of the flame as a function of time.

The rate of flame area increase is proportional to the square of the flame speed through the dust cloud, the flame front velocity. The flame front velocity is also used to determine when the deflagration flame constraint by the building occurs.

The flame speed through the dust suspension, S_u, can be computed from test data for K_{St}.[31]

$$S_u = K_{st} / 4.84\left[(P_{\max} / P_0) - 1\right]P_{\max}$$ [V.3.2.2d]

where:

K_{St} = measured deflagration index obtained per ASTM E 1226

P_{max} = maximum deflagration pressure (bar)

P_0 = initial pressure (bar)

This relation provides the rate at which the radius of a spherical deflagration flame and hence the circular radiant emitter is increasing until wall constraint occurs. This provides the rate of radiating area increase.

Once wall constraint occurs the radiating area of the deflagration is limited to the compartment cross-section, but the flame front accelerates towards the target occupant. Eckhoff offers a relation for the speed of the flame front (see Equation V.3.2.2e). [32]

$$S_f = S_u + S_g$$ [V.3.2.2e]

where:

S_f = speed of the flame layer relative to a stationary point, the occupant

S_u = flame speed through the dust cloud, the fundamental burning velocity

S_g = speed of the surface of the combustion product gas volume

Eckhoff also states that under ideal, adiabatic conditions the ratio S_f / S_u is approximately 7.5 for most organic compound fuels. [33] Eckhoff notes that this is also the combustion product expansion ratio, the final deflagration product volume to initial fuel suspension volume, for this category of fuels. [34] (Eckhoff uses the *E* for this parameter, we use *Z* to avoid confusion with the parameter *E* used above in Equation V.3.2.1.2a.)

$$S_f = S_u Z \quad \text{[V.3.2.2f]}$$

This relation provides an estimate of the flame front velocity through the dust cloud. For metallic particulates, an expansion ratio of 10:1 is commonly used since the expansion ratio is generally proportional to the measured P_{max} to ambient ratio.

Once an estimate for the flame speed has been developed, one can estimate the radiant flux from the expanding deflagration using the area of an optically dense circular radiator to model the deflagration flame for the time period before wall constraint. Since the BCD scenario contemplates a pre-existing dust cloud, the atmospheric extinction should be included in the calculation. Either Equation V.3.2.1.4f or V.3.2.2a can be used to compute the radiant flux intensity at a target occupant located a given distance from the deflagration. If an average emissive power is used for the deflagration as in Equations V.3.2.1.2a and V.3.2.1.2b, and Θ = 90 degrees, cos Θ = 1. Equation V.3.2.1.4f can then be rewritten as Equation V.3.2.2g.

$$q" = e^{-\mu L}(350\ \mathrm{kW/m^2})(r^2/L^2) \quad \text{[V.3.2.2g]}$$

This relation allows one to compute the radiant flux intensity on the occupant as the deflagration flame front advances towards that occupant in a succession of short time intervals. This allows one to estimate how long after ignition the conditions at the target exceed the criteria for the personal injury prevention objective for the facility.

V.3.2.3 Using the Relations for a BCD.

In the BCD scenario there is either a pre-existing dust suspension in the building compartment atmosphere, or the mechanical impulse from the initial flame front expansion (pressure, shear force, vibration) suspends dust that has accumulated to hazardous levels within the building compartment. Since the deflagration flame volume is increasing in time, a simple explicit relation does not suffice to identify the point when the conditions exceed the personnel protection criterion.

In the initial phase of the deflagration, before constraint by the building compartment enclosure, Equation V.3.2.1.1, V.3.2.1.2a, or V.3.2.1.3 can be used to compute the radiant flux intensity on the occupant as a function of time. This can be done by step-wise, successive calculation using a spreadsheet such as Excel or the equivalent.

Using a flame speed, S_u, of 0.62 m/sec (a value from research Eckhoff cites for corn starch) [35], the expected flame front velocity, S_f, would be 4.65 m/sec. This is the rate the radius of a circular radiating area of the unconstrained deflagration flame is increasing. (Keep in mind this numerical value is only appropriate for corn starch.) Since the flame front is an optically dense radiator, the radiating surface facing a target occupant is circular. This leads to an estimate for the radiating surface area 1.0 second after ignition of 67.9 m^2. Another second later the deflagration flame has a diameter of 18.6 m unless the building compartment floor, ceiling, or walls constrain the expansion.

Once the deflagration flame becomes constrained by the building, the radiating area of the deflagration stops increasing. However, the flame front continues to advance as a solid wall of flame across the building compartment interior. The flame front velocity is S_f. The increase in radiant flux intensity impinging on a target occupant increases due to the reduction in separation distance due to the flame front travel. Once floor, wall, or ceiling constraint is predicted by the deflagration volume calculation, the spreadsheet formulae should be modified for constant radiating area but advance towards the target.

Some references organize the relation used to predict the radiant flux intensity (kW/m^2) impinging on the occupant to include both a configuration factor, φ, (also called the view factor) and the $e^{-\mu L}$ optical transmission losses from the Beer-Lambert Law. The received radiant flux intensity can be computed from Equation 3.2.2.3a. [36]

$$q'' = E\phi e^{-\mu L}$$ **[V.3.2.3a]**

where:

E = emissive power of deflagration flame (kW/m^2)

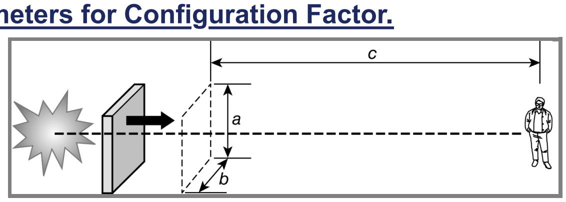
φ = configuration factor, unitless fractional value

$e^{-\mu L}$ = Beer-Lambert Law atmospheric absorbance, unitless fractional value

q'' = received radiant flux intensity (kW/m^2)

The configuration factor, φ, combines the various geometrical relations into a single factor. It is calculated for the geometric relationship between the radiator and the target. For a rectangular radiator the configuration factor reflects the dimensional designations shown in Figure V.3.2.3. Under the scenario with no dust accumulations that can be suspended and cause optical absorbance of the air, the $e^{-\mu L}$ term reduces to 1.

Figure V.3.2.3 Parameters for Configuration Factor.



For the planar flame front depicted in Figure V.3.2.3, the configuration factor, also called view factor, is computed with Equation V.3.2.3b. [37]

$$F_{1,2} = 2/\pi\left[\frac{X}{(1+X^2)^{1/2}}\tan\text{-}1\left[\frac{Y}{(1+X^2)^{1/2}}\right]+\frac{Y}{(1+Y^2)^{1/2}}\tan^{-1}\left[\frac{X}{(1+Y^2)^{1/2}}\right]\right] \quad \textbf{[V.3.2.3b]}$$

where:

X = a/c

Y = b/c

Once the event becomes constrained by the building structure, the expansion of the BCD is determined by the building compartment geometry. This computational estimate is dependent on the specific building compartment dimensions. Furthermore, it is only credible under the following conditions:

(1) There is sufficient vent area in the compartment walls to prevent an increase in pressure ahead of the flame front in the pre-existing dust suspension.

(2) There is no increase in combustion rate due to turbulence.

To illustrate the process of estimating radiant flux exposure for the purpose of assessing personnel protection needs and options, consider a building compartment as pictured in Figure V.3.2.2(a) that is 30 m wide, 8 m from floor to ceiling, and 50 m long. The occupant is located 5 m from an end wall, and the ignition occurs 5 m from the opposite end wall. The building compartment has dust accumulations on all upward-facing horizontal surfaces in excess of 5 cm deep. The dust is corn starch with MEC = 50 g/m^3 and c_w = 400 g/m^3.

As with the inherently limited deflagration in V.3.2.1, estimating the radiant flux on a target occupant from a BCD involves computing the radiating area of the flame, but in the BCD scenario it is done as a function of time. The rate of flame area increase is proportional the square of the flame speed, S_u, through the dust cloud. S_u can be used to determine the radius of the deflagration flame at increments in time after ignition. This allows the determination of radiating area at each increment in time.

Once an estimate for the flame speed has been developed, one can estimate the radiant flux on a target occupant from a BCD at selected points in time to evaluate protection needs and limitations. This is done as a two-step process. First the radiant flux on the occupant is computed for an unconstrained deflagration until the flame becomes constrained by the ceiling, walls, or floor. Once constraint occurs, the calculation is modified to approximate the deflagration as a rectangular sheet of flame occupying the cross-sectional area of the compartment, moving across the compartment long dimension towards the target occupant.

$$q" = X_r(Qe^{-\mu L}/4\pi L^2)\cos\Theta \quad \textbf{[V.3.2.3c]}$$

Equation V.3.2.3c requires a numerical value for Q, the heat release rate. One can use the experimentally derived value of 350 kW/m^2 multiplied by the radiating area for Q as shown in Equation V.3.2.1.2b. When this value is used it already includes the application of the parameter X_r.

In the alternative, Q can be computed from the deflagration flame volume, v_f, at time, t, the dust concentration, c, the net heat of combustion, ΔH_c, a correction for the combustion efficiency, η, and a correction factor for the fraction of the radiant power radiated towards the target. This provides the energy release, H_c, but not the heat release rate, Q. Q is defined as dH/dt, but sufficient precision for the purposes of this annex can be had by approximating dH/dt with $\Delta H/\Delta t$ and using the heat release, MJ, as the average heat release rate, MW, for the 1 second time interval centered on the point in time under consideration.

When this calculation is used, the radiant fraction, X_r should be included. Since dust deflagrations are generally fuel rich, the flame intermediate compounds leave the combustion zone incompletely oxidized, reducing the quantity of heat from the reaction. ΔH_c is for complete combustion in a cone calorimeter, not a diffusion flame through a dust cloud. A correction, η, for combustion efficiency is added and will have a value less than 1.0.

The radiant flux from a deflagration flame is emitted towards the target, the direction opposite of towards the target, to the left, right, up, and down, and the fraction emitted towards the target is 1⁄6 the total radiant flux. This leads to the relation in Equation V.3.2.3d.

$$Q = (v_f c \Delta H_c / \Delta t)(X r \eta)/6 \quad \text{[V.3.2.3d]}$$

where:

v_f = volume of deflagration flame at time (t)

c = dust concentration (kg/m^3)

η = combustion efficiency

Δt = 0.5 sec

The following numerical values can be used as initial inputs:

X_r , radiative fraction of the heat release (fractional value) = 0.35

ΔH_c , net heat of combustion = 16.2 MJ/kg

η, combustion efficiency = 0.9

μ, Beer-Lambert absorbance coefficient = 0.3

Θ, angle of hypothetical target plane to flame exposure path = 90 degrees

The received radiant flux (kW/m^2) on the target occupant can be computed for increments in time. The results are provided for conditions of no atmospheric obscuration (clear air, μ = 0) and conditions of a dust cloud of a material like cornstarch (μ = 0.3).

To make the computational simulation more realistic, parameters were adjusted at steps in time. The combustion efficiency, η was adjusted to 0.7 after 0.5 seconds. After 0.5 seconds the deflagration flame volume of the previous increment was subtracted from the flame volume when computing flame volume. This volume was also added to the formula for calculating separation distance to accelerate the flame towards the target. Once the deflagration flame became constrained by the walls, floor, and ceiling the radiating area, flame volume, and emitted radiant flux were held constant, and the increase in received flux intensity is due to the reduction in separation distance. The predicted results are shown in Table V.3.2.3 .

Table V.3.2.3 Predicted Results of a BCD Event

Time, *t* , sec	**Radius, m**	**Radiating Area, m^2**	**Flame Volume, m^3**	**Emitted Radiant Flux, MW**	**Separation Distance, m**	***q"* μ = 0 kW/m^2**	***q"* μ = 0.3 kW/m^2**
0.5	2.33	17	52.6	5.59	37.7	0.1	<<0.1
1	4.65	67.9	368.2	60.9	35.1	8.3	<<0.1
1.5	6.98	152.8	1052	261	31.5	29.6	<<0.1
2	NA	240	2,315	766	26.3	93.1	0.1
2.5	NA	240	2,315	766	18.7	184	0.25
3	NA	240	2,315	766	16.4	240	0.3
3.5	NA	240	2,315	766	14.1	325	0.4
4	NA	240	2,315	766	11.8	466	0.6
4.5	NA	240	2,315	766	9.4	725	1
5	NA	240	2,315	766	7.1	1,278	1.8
5.5	NA	240	2,315	766	4.8	2,824	3.9
6	NA	240	2,315	766	2.5	10,711	14.8

Time, *t*, sec	Radius, m	Radiating Area, m^2	Flame Volume, m^3	Emitted Radiant Flux, MW	Separation Distance, m	*q"* μ = 0 kW/ m^2	*q"* μ = 0.3 kW/ m^2
6.5	NA	240	2,315	766	0.1	3.87×10^6	5.33×10^3

At the end of the first increment in time, 0.5 seconds after ignition, the incident radiant flux on the target occupant is too small to be noticed due to separation distance. Note that the emitted radiant flux divided by the circular radiating area is 330 kW/m^2, quite close to the 350 kW/m^2 used in Equation V.3.2.1.2b.

The calculated radiant flux at the target occupant location can be compared to the performance criteria selected in accordance with V.2.3 and V.2.4 to determine whether FRG is needed to achieve the personnel safety objectives, and, if so, whether FRG can provide the level of personnel protection needed to achieve that same objective.

Using one of the methods in the previous paragraphs, one can compute an estimate for the radiant flux intensity impinging on the occupant. The calculated thermal dose can be compared to that associated with the level of tolerable injury. If the thermal dose intensity at the occupant location exceeds the that sufficient to cause third-degree burns on unprotected skin, third-degree burns are expected to result. Also, if the thermal dose at the occupant location exceeds that sufficient to ignite clothing, third-degree burns are expected to occur due to occupant exposure to burning clothing. In these examples, the personnel injury limitation objective criterion has been exceeded, and fatality is likely. [38] If the estimated thermal flux intensity is determined to be capable of igniting ordinary clothing, the use of FRG is necessary. This does not necessarily imply that FRG is capable of achieving the injury prevention objective. There are limits to the thermal protection capabilities of FRG. It only means that FRG can provide a measure of protection that might be sufficient to reduce the severity of burn injuries in some cases. Refer to V.4.1 for additional perspective on limitations of the protective capability of FRG.

V.3.2.4 Estimating Deflagration Flame Impingement Hazard.

The radiant flux intensity estimate in V.3.2.1 or V.3.2.2 is based upon modeling the deflagration as occurring rapidly and with a radiating area derived from the pre-ignition dust suspension volume. This allows one to obtain a bounding-value estimate of the radiant flux intensity on a target at a defined separation distance. The radiant flux is modeled as uniformly distributed throughout the dust suspension volume abruptly and as an optically dense radiator having a circular radiating area until it becomes constrained by the building compartment walls, floor, and ceiling. In order to rely on a radiant flux model, the assumption that there is no piloted ignition by the deflagration flame should be confirmed.

One method to obtain an estimate for the distance an igniting flame will extend from a deflagration originating in a piece of equipment and directed through an opening such as an open chute at a bag unloading station is to use the vented deflagration fireball calculation outlined in 6.8.3 of NFPA 68 . [39]

A second method to obtain an estimate for flame extension for a localized, unconfined dust cloud is to compute the flame volume of the burning cloud by applying the ideal gas law to the experimentally determined P_{max} value for the material. P_{max} is a ratio between the maximum pressure and initial pressure in a constant volume environment, and by the ideal gas law this would be equivalent to the ratio of the final volume to the initial volume for a constant pressure environment, assuming adiabatic boundary conditions and comparable combustion characteristics in the two scenarios. The flame volume expansion factor is simply equated to the numerical value for P_{max} .

A third strategy for obtaining an estimate for the distance an igniting flame will extend from a deflagration can be derived from the combustion chemistry. The deflagration flame volume can be modelled as occupying the entire dust suspension volume at the adiabatic flame temperature and then expanding according to the ideal gas law. The flame temperature is then derived from the combustion chemistry.

A dust deflagration involving nonmetallic particulates like plastics, agricultural products, paper, and forest products can be approximated by using common corn starch and the chemical equation shown in Equation V.3.2.4a.

$$C_6H_{10}O_5 + 6\ O_2 \Rightarrow 6\ CO_2 + 5\ H_2O + \text{Heat} \quad \textbf{[V.3.2.4a]}$$

Normalizing this stoichiometric equation for 1.0 m^3 of air yields Equation V.3.2.4b.

$$1.54\ C_6H_{10}O_5 + 9.26\ O_2 + 34.7\ N_2 + 0.63\ Ar \Rightarrow 9.26\ CO_2 + 7.71\ H_2O + 34.7\ N_2 + 0.63\ Ar + \text{Heat} \quad \textbf{[V.3.2.4b]}$$

In addition to the 17.3 percent volumetric expansion due to the increase in the number of moles of gaseous combustion products, there is the liberated heat that will cause the combustion products gas to expand.

$$(470\ \text{kJ/mole}\ O_2)(9.26\ \text{mole}\ O_2) = 4{,}352\ \text{kJ Heat} \quad \textbf{[V.3.2.4c]}$$

This heat is liberated into the combustion product gas. The resulting temperature of the gas can be computed using Equation V.3.2.4d.

$$\Delta T = \Delta H / mc_p \quad \textbf{[V.3.2.4d]}$$

where:

ΔH = liberated heat of combustion (4,343 kJ)

m = mass (g)

c_p = specific heat (j/mole K)

ΔT = change in temperature (K)

The temperature increase due to the combustion reaction is computed with Equation V.3.2.4e.

$$\Delta T = \Delta H / \left(m_{CO_2} c_{PCO_2} + m_{H_2O} c_{PH_2O} + m_{N_2} c_{PN_2} + m_{Ar} c_{PAr} \right) \quad \textbf{[V.3.2.4e]}$$

Using the values in Table V.3.2.4 leads to a computed temperature increase for the reaction normalized to 1.0 m^3 in volume. For this example, we used values for c_p at

1200 K as an average probable flame temperature.

Table V.3.2.4 Gas Properties

Gas	CO_2	H_2O	N_2	Ar
Mass (g/m^3)	401	139	972	25.2
c_p @ 1200 K [41], j/gK	1.28	2.43	1.24	0.523

$$\Delta T = 2097.6\,\mathrm{K} \quad \text{[V.3.2.4f]}$$

If the reaction occurred at a 300 K ambient temperature, the deflagration flame temperature is estimated to be approximately 2,397 K. This combustion temperature is derived from the chemical equation of the combustion of starch. Due to the similarity of the chemical compounds constituting wood, cellulosic, and other agricultural products, similar results can be expected for those particulates. However, since this estimate assumes complete stoichiometric combustion and does not take into account endothermic pyrolytic processes, the user should select a reasonable bounding value for the temperature estimate. Furthermore, the chemical equation used here does not reflect the combustion of a metallic fuel. For metallic fuels, an explicit chemical equation for the specific fuel should be used.

As the combustion product gas expands against the ambient air it cools. The resulting temperature as a function of distance from the initial dust suspension surface can be computed by using the ideal gas law relation in Equation V.3.2.4g.

$$\frac{P_1 V_1}{n_1 R T_1} = \frac{P_2 V_2}{n_2 R T_2} \quad \text{[V.3.2.4g]}$$

The “1” subscripts refer to the initial deflagration at ignition, and the “2” subscripts refer to the post expansion conditions. This relation assumes ideal conditions and that the expanding deflagration product gas expands without mixing with ambient air. Since mixing with cool ambient air results in a mixture of lower temperature, mixing does not expand the distance at which hazardous temperatures exist.

This relationship allows us to compute the volume occupied by the deflagration product gases when they have expanded and cooled to the temperature used for the life safety criteria derived from the objectives.

The ignition of ordinary street clothing made of cotton and polyester fabrics has been widely studied. Ignition onset has been reported by some researchers when “ordinary clothing” is exposed to radiant flux on the order of 50 kW/m^2 . Other research reports the onset of ignition when temperatures of 200°C to 300°C (473 K to 573 K) are attained. These criteria can be used establish the minimum separation distance between the initial, pre-ignition dust suspension and the target personnel when the ignition of clothing by a piloted ignition of clothing by the deflagration flame is the safety criterion. [42,43]

Using the values for starch as a surrogate for the combustible dust in the hazard area, the deflagration flame will cease to be sufficiently hot to ignite clothing when the gas volume has increased by a factor of 5 to 4.2, depending upon the ignition characteristics of the clothing involved. As long as personnel are reliably prevented from being closer to the surface of the deflagration flame than the diameter attained when the temperature has decreased to the applicable ignition temperature, the combustion product gases would not be expected to ignite clothing.

This applicability of the result is limited by the assumptions regarding the combustion event. First and foremost, it assumes there is no entrained dust in the effluent combustion product gases. Is this a credible assumption? Any entrained dust will burn once it is exposed to fresh air at the flame/ambient interface. This calculation does not account for this. Entrained dust is expected to extend the flame front further than the calculation suggests. Second, this value is for the carbon-containing fuels similar to starch. The accuracy of this separation distance estimate can be improved by using the chemical equation for the fuel present in the specific hazard area. However, the uncertainty introduced by the possibility of entrained dust might exceed any improvement in precision attained with a more specific chemical equation.

Third, the use of this separation distance estimate method is not applicable to metallic particulate deflagrations due to the differences in the combustion chemistries, the heats of combustion, and resulting flame temperatures for metallic particulate deflagrations.

Remain mindful that any calculation of deflagration flame extension is predicated on all of the assumptions that served as the basis for the calculation. Using the worst-case concentration, c_w, might not produce the largest flame extension volume. A fuel-rich deflagration will probably expel unburned dust beyond the initial dust suspension, where additional combustion air becomes available, extending the flame front. How far is unknown. When performing a calculation to model flame extension, each assumption must be made using values that produce a worst-case estimate. Furthermore, safety-factors that address the multiple uncertainties should be applied. Finally, remain mindful that these calculations assume that there are no dust accumulations present in the building compartment that can become suspended, entrained, and ignited, thereby adding fuel and extending the flame volume beyond the initial deflagration. If there are dust accumulations in the building compartment interior, transition to a building compartment deflagration should be expected.

V.4 Evaluating Personnel Protection Options.

Once the flash fire scenarios are developed, the thermal flux exposure for each scenario can be computed as a function of the occupant location relative to the epicenter of the initial ignition and expansion of the deflagration flame front. Relations shown in V.3.2.1 or V.3.2.2 allow the user to compute the radiant flux intensity (kW/m^2) at the exposed surface of known occupant locations. Those relations can be used to determine if separation distance control can achieve the injury prevention objective. Other relations shown in V.3.2.4 can be used to predict deflagration flame extension distance. These second relations can be used to determine if piloted ignition by the deflagration flame at a given occupant location is likely.

For those cases where piloted ignition by the deflagration flame is not predicted in the flash fire scenario, the thermal flux is limited to the radiant flux. The radiant flux intensity that reflects the injury limitation objective can be used to determine if the personnel protection objectives can be achieved with a strategy of controlling separation distance.

In those cases where either piloted ignition by the deflagration flame or radiant flux sufficient to ignite ordinary clothing cannot be precluded, the ignition of ordinary clothing is to be expected. Once an occupant's clothing ignites, fatal burn injury often results. As a consequence, FRG is needed wherever ignition of the occupant's clothing is possible. This does not imply that FRG is capable of achieving the injury prevention objective. There are limits to the thermal protection capabilities of FRG. It only means that FRG can provide a measure of protection that might be sufficient to reduce the severity of burn injuries in some cases. The analytical methods presented here are not capable of demonstrating that a certain degree of injury can be prevented with the use of FRG in the above scenarios. Consequently, the use of FRG cannot be expected to prevent injury or fatality in the event of a building compartment deflagration.

If a flash fire resulting from a building compartment deflagration fueled by accumulated fugitive dust is possible, engulfment of occupants is likely. The thermal flux intensities and separation distances between the deflagration flame front and the occupants are both unpredictable but expected to exceed the protective capabilities of FRG. FRG should not be relied upon to achieve a personnel protection objective. The use of FRG can contribute some reduction of the severity and probability of injuries when the fire event does not attain the worst-case severity, but there is also the possibility that it will not. Consequently, the dust accumulations should be eliminated and the facility interior maintained below the dust accumulation levels that allow a building compartment deflagration to occur. See Section 8.4 and associated Annex A material. Annex S provides information on assessing dust accumulation to address the potential for a BCD.

V.4.1 Limitation on the Reliance on FRG.

The stated intent of FRG under NFPA 2112 is "not contributing to the burn injury of the wearer, providing a degree of protection to the wearer, and reducing the severity of burn injuries resulting during egress from or accidental exposure to short-duration thermal exposure." [44] NFPA 2112 states that garments shall be tested in accordance with the standard and shall result in an average predicted body burn of not more than 50 percent with no single burn being equal to or greater than 55 percent based on the total surface area covered by sensors, excluding hands and feet. This standard does not state how severe the burns are permitted to be. Third-degree burns over 50 percent of the body are usually taken to be fatal. [45]

NFPA 2113 states: "Flame-resistant garments can reduce the severity of burn injury as a result of a fire but cannot completely prevent an injury." [46] NFPA 2113 uses a pass/fail test criterion of a thermal dose of 252 kJ/m^2 (84 kW/m^2 for 3.0 seconds) applied to the garment. [47] The pass/fail test criterion is used to indicate whether or not the computer model used for the testing indicates that the garment would allow more than 50 percent burns overall or a single burn being equal to or greater than 55 percent based on the total surface area covered by sensors. But it does not provide information regarding the effect this thermal dose will have on the user of the FRG. NFPA 2112 also uses the 84 kW/m^2 radiant flux for 3 seconds, conducted in accordance with ASTM F1930, *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin* , for the full body acceptance test. [48]

FRG is tested in accordance with ASTM F1930. [49] The test uses multiple propane burners with flame adjusted to produce a yellow-to-red flame. [50] A manikin equipped with a minimum of 100 thermal sensors attached to and located across its exterior surface is clothed in the FRG under test and exposed to the burners for a set time. [51]

The thermal energy sensors generate data from which the heat flux at the skin at each sensor location and its variation with time can be calculated. The time/temperature history data for the sensors is recorded. This data is used to compute the time/temperature exposure of the manikin,and the severity of the burn injury to a human wearing the manikin is computed from a burn injury model. [52]

The model computes the rate of increase of burn injury factor, dΩ/dt, from the relation in Equation V.4.1a. [53]

$$d\Omega / dt = P \exp(-\Delta E/RT) \qquad \textbf{[V.4.1a]}$$

where:

$d\Omega/dt$ = rate of increase in the burn injury factor, Ω, per unit time

T = epidermal skin temperature (K)

R = ideal gas constant (8.314 kJ/kmole K)

P = experimentally derived factor (sec^{-1})

ΔE = experimentally derived activation energy (kJ/kmole)

t = time duration the skin temperature exceeds 44°C (317.2 K)

The accumulated skin damage is computed by integrating the relation to obtain Equation V.4.1b. [54]

$$\Omega = \int_0^t P \exp(-\Delta E/RT)\, dt \qquad \textbf{[V.4.1b]}$$

Second-degree burn injury is predicted when the magnitude of Ω ≤ 1.0 at the dermis/epidermis interface depth and third-degree burns are predicted for magnitudes of Ω ≥ 1.0 at the dermis/subcutaneous (adipose) tissue interface depth.

The computer model computes the value of Ω as a function of location on the body and assigns an injury severity for that fraction of the body area. The injury-area products are then combined to yield a prediction of the percent body area with second-degree burns and the percentage of body area with third-degree burns to the wearer's body. [55] The acceptance criterion is less than 50 percent of the body surface receiving second- or third-degree burn injury. [56] The user can conclude that a thermal dose of 252 kJ/m^2 will likely lead to second- and third-degree burns over up to 50 percent of the wearer's body surface.

A simplified example in the CCPS *Guidelines for Chemical Process Quantitative Risk Analysis* predicts a 50 percent probability of fatality for a thermal flux of 85.2 kW/m^2 for an exposure time of 10 seconds. [57] The thermal flux value differs from the 84 kW/m^2 thermal flux referenced in NFPA 2112 . Additionally, 3 second exposure time referenced in A.4.3 of NFPA 2113 is much shorter than the 10 second exposure duration used by CCPS.

The CCPS estimate is obtained by using probit equations. (A probit function is a mathematical operation on a Gaussian probability distribution that converts a dose-response curve into an approximately straight line.) Probit equations for the probit variable, Y, are based upon a causative variable, V, and at least two constants, k_1 and k_2, using an equation of the form shown in Equation V.4.1c.

$$Y = k_1 + k_2 \ln V \qquad \textbf{[V.4.1c]}$$

The probits (probability units) are converted into percentages using a table. [58] The probit equation is used to determine the thermal flux intensity that is expected to result in third-degree burns over 50 percent of the body from an exposure of given duration. This reference reports that the probit equations are contemplating "lightly clothed" occupants. [59] No quantitative relation is provided for occupants equipped with FRG.

V.5 Summary of Hazard Management Strategy Development.

V.5.1 Establish Objectives for Personnel Safety.

The first step in assessing the workplace hazard management is establishing clear objectives for personnel safety. The facility operator should document its personnel safety objectives.

V.5.2 Establish Clear Performance Criteria.

The personnel safety objectives should be used to establish clear performance criteria. The performance criteria should be measurable and expressed quantitatively. The facility operator should document its personnel safety performance criteria.

Examples of values for various criteria for unprotected occupants are as follows: [60]

Pain threshold: 41.9 kJ/m^2

Blister, severe second-degree burn: 83.8 kJ/m^2

Severe third-degree burn: 162.5 kJ/m^2

Performance criterion for FRG: 252 kJ/m^2 [61]

V.5.3 Identify Flash Fire Hazard Areas.

All locations in the dust-handling building compartment that can support a dust deflagration and pose a flash fire hazard to the occupants should be identified. The facility operator should document the deflagration and flash fire hazards.

It has been mentioned in V.4.1 that once an occupant's clothing ignites, the resulting injury is usually fatal third-degree burns. The available technology is the use of FRG for employees exposed to the potential for the ignition of their clothing. The workplace hazard assessment first identifies those areas within the facility where employees are exposed to the potential of clothing ignition and where they are not. Those areas where employees are exposed to the potential of clothing ignition from flash fires are identified as areas where FRG use should be required.

V.5.4 Determine Radiant Heat Flux Exposures.

The radiant flux that would impinge upon an occupant located at the nearest location to the deflagration epicenter should be computed for each flash fire scenario.

V.5.5 Determine Where Each Level of Personnel Protection Is Both Necessary and Sufficient.

If the calculated radiant flux exceeds the criteria selected by the facility operator for personnel injury prevention, the affected employees should be equipped to preclude injury.

V.5.5.1

Where the predicted radiant flux in an occupiable location is sufficient to cause ignition of ordinary clothing, that location should be identified as requiring FRG use.

V.5.5.2

Employees permitted to occupy locations where FRG is required should be equipped with FRG designed in accordance with NFPA 2112 and used in accordance with NFPA 2113 .

V.5.5.3

Employees should not be permitted to occupy locations where the predicted radiant flux intensity exceeds the performance criteria of the FRG.

V.5.5.4

Protection should be provided for the body as well as the head, face, and hands.

V.5.6 Determine Where Flames Could Engulf Occupants.

The maximum deflagration flame extension distance should be computed for each flash fire scenario.

If the calculated flame extension distance exceeds the minimum applicable personnel separation from the deflagration epicenter, affected employees should be equipped with FRG designed in accordance with NFPA 2112 and used in accordance with NFPA 2113 .

Protection should be provided for the head, face, and hands as well as the body.

Flame impingement should be expected to lead to the ignition of ordinary clothing. Clothing ignition is expected to lead to severe third-degree burns and fatality. [62]

V.5.7 Consider Limitations of Protective Capability of FRG.

It has been mentioned in V.4.1 that once an occupant's clothing ignites, the resulting injury is usually fatal third-degree burns. The available technology is the use of FRG for employees exposed to the potential for the ignition of their clothing. The workplace hazard assessment in V.5.3 first identifies those areas within the facility where a flash fire potential exists.

Those areas where employees are exposed to the potential of clothing ignition from flash fires are identified as areas where FRG use should be required. However, FRG should not be expected to prevent injury to occupants located in building compartments with fugitive dust accumulations in excess of the threshold housekeeping levels stipulated in this standard (i.e., where there is a likely potential for a BCD).

Furthermore, FRG does not address the injurious effects of inhaling hot combustion product gases from a deflagration. Airway searing can result in pulmonary failure. Combustion product gases are typically comprised of toxic chemical compounds including carbon monoxide, formic acid, formaldehyde, and metal carbonyls where metallic particulates are involved.

Notwithstanding the finite thermal protective capabilities of FRG, it still could be wise to use it as a safeguard for those situations where the worst-case exposures do not occur, as long as it is recognized FRG might not be capable of preventing injuries in all cases.

V.6 References.

(1) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," pp. 8, 12, Table 2.1, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(2) Babrauskas, Vytenis, PhD, *The Ignition Handbook* , pp. 816, 822, Fire Science Publishers, Issaquah, WA, 2003.

(3) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," p. 25, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(4) Howel, Menguc, Daun, and Siegel, *Thermal Radiation Heat Transfer* , 7th edition, p. 140, CRC Press, Boca Raton, FL, 2021.

(5) The SFPE Task Group on Engineering Practices, *Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation* , p.18, Society of Fire Protection Engineers, Bethesda, MD, 2000.

(6) Ibid., p. 8.

(7) Hurley, Morgan, PE, FSFPE, editor-in-chief, SFPE *Handbook of Fire Protection Engineering* , 5th edition, p. 2720, Springer, NY, 2016.

(8) Ibid., p. 2723.

(9) Ibid.

(10) Ibid., Chapters 66 and 67.

(11) NFPA 72, *National Fire Alarm and Signaling Code* , 2025 edition, Section 17.8, National Fire Protection Association, Quincy, MA, 2025.

(12) Drysdale, Dougal, *An Introduction to Fire Dynamics* , 3rd edition, pp. 165–169, John Wiley & Sons, West Sussex, UK, 2011.

(13) Hurley, Morgan, PE, FSFPE, editor-in-chief, SFPE *Handbook of Fire Protection Engineering* , 5th edition, p. 2654, Springer, NY, 2016.

(14) Ibid.

(15) Ibid.

(16) Beyler, C., "Fire Hazard Calculations for Large, Open Hydrocarbon Fires," SFPE *Handbook of Fire Protection Engineering* , 5th edition, Chapter 66, Hurley, M., editor-in-chief, Springer, NY, 2016.

(17) Hurley, Morgan, PE, FSFPE, editor-in-chief, SFPE *Handbook of Fire Protection Engineering* , 5th edition, p. 2655, Springer, NY, 2016.

(18) CCPS *Guidelines for Chemical Process Quantitative Risk Analysis* , 2nd edition, p. 209, Center for Chemical Process Safety, American Institute of Chemical Engineers, NY, 2000.

(19) Hurley, Morgan, PE, FSFPE, editor-in-chief, SFPE *Handbook of Fire Protection Engineering* , 5th edition, p. 2655, Springer, NY, 2016.

(20) Beyler, C., "Fire Hazard Calculations for Large, Open Hydrocarbon Fires," SFPE *Handbook of Fire Protection Engineering* , 5th edition, Chapter 66, p. 2654 et seq., Hurley, M., editor-in-chief, Springer, NY, 2016.

(21) Siegel and Howell[KC49.1][LM49.2][, p. 1035, App C.

(22) Drysdale, Dougal, *Introduction to Fire Dynamics* , 2nd edition, pp. 37 et seq., John Wiley & Sons, NY, 2011.

(23) Ibid., pp. 77, 129, 148–149.

(24) Cashdollar, Kenneth and Zlochower, Isaac, *Explosion Temperatures of Metals and Other Elemental Dust Clouds* , Pittsburg Research Laboratory, National Institute for Occupational Safety and Health, https://stacks.cdc.go>cdc>cdc_8762_DS1-4.pdf.

(25) Hurley, Morgan, PE, FSFPE, editor-in-chief, SFPE *Handbook of Fire Protection*

Engineering , 5th edition, Table A.33, p. 3449, Springer, NY, 2016.

(26) Zalosh, Robert G., PhD, PE, *Industrial Fire Protection Engineering* , pp. 337–346, John Wiley & Sons, West Sussex, UK, 2003.

(27) Rockwell, Scott R. "Influence on Coal Dust on Pre-Mixed Turbulent Methane-Air Flames," p. 17, doctoral dissertation, Worcester Polytechnic Institute, 2012.

(28) Castellan, Gilbert W., *Physical Chemistry* , p. 664, Addison-Wesley Publishing Co., Reading, MA, 1964.

(29) Howel, Menguc, Daun, and Siegel, *Thermal Radiation Heat Transfer* , 7th edition, p. 37, CRC Press, Boca Raton, FL, 2021.

(30) Eckhoff, Rolf K., *Dust Explosions in the Process Industries* , 3rd edition, p. 9, Gulf Professional Publishing, Elsevier, Burlington, MA, 2003.

(31) Rockwell, Scott R., "Influence on Coal Dust on Pre-Mixed Turbulent Methane-Air Flames," p. 17, doctoral dissertation, Worcester Polytechnic Institute, 2012.

(32) Eckhoff, Rolf K., *Dust Explosions in the Process Industries* , 3rd edition, p. 271, Gulf Professional Publishing, Elsevier, Burlington, MA, 2003.

(33) Ibid.

(34) Ibid.

(35) Ibid., p. 281.

(36) Zalosh, Robert G., PhD, PE, *Industrial Fire Protection Engineering* , p. 342, John Wiley & Sons, West Sussex, UK, 2003.

(37) Ibid., p. 343.

(38) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," p. 25, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(39), NFPA 68, *Standard on Explosion Protection by Deflagration Venting* , 2023 edition, Section 6.8.3, National Fire Protection Association, Quincy, MA, 2023.

(40) Eckhoff, Rolf K., *Dust Explosions in the Process Industries* , 3rd edition, p. 6, Gulf Professional Publishing, Elsevier, Burlington, MA, 2003.

(41) https://www.engineeringtoolbox.com/html.

(42) Babrauskas, Vytenis, PhD, *The Ignition Handbook* , p. 816, 822, Fire Science Publishers, Issaquah, WA 2003.

(43) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," p. 25, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(44), NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire* , 2023 edition, Section 1.2.1, National Fire Protection Association, Quincy, MA, 2023.

(45) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," p. 25, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(46). NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire* , 2025 edition, Section A4.3, National Fire Protection Association, Quincy, MA, 2025.

(47) Ibid., Section A.4.3.

(48) NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire* , 2023 edition, Section 8.5.6.1, National Fire Protection Association, Quincy, MA, 2023.

(49) Lovasic, Susan L., and Neal, Thomas E., PhD, *Industrial Flash Fire and Burn Injury Fundamentals with an Instrumented Manikin Demonstration of Protective Clothing Performance* , ASSE Professional Development Conference and Exposition, 2002.

(50), ASTM F1930, *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin* , Section 6.7.3.1, ASTM International, West Conshohocken, PA, 2018.

(51) Ibid., Section 6.2.2.

(52) Ibid., Section 6.5.3.1

(53) Ibid., Section X1.4.

(54) Ibid., Section X1.5.

(55) Ibid., Section 13.5.

(56) NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire* , 2023 edition, Section 7.1.5, National Fire Protection Association, Quincy, MA, 2023.

(57) CCPS *Guidelines for Chemical Process Quantitative Risk Analysis* , 2nd edition, p. 246, Center for Chemical Process Safety, American Institute of Chemical Engineers, NY, 2000.

(58) Ibid., p. 247.

(59) Ibid., p. 270.

(60) The SFPE Task Group on Engineering Practices, *Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation* , p. 18, Society of Fire Protection Engineers, Bethesda, MD, 2000.

(61) NFPA 2113, *Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire* , 2025 edition, Section A4.3, National Fire Protection Association, Quincy, MA, 2025.

(62) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage* , "TNO Green Book," pp. 8, 12, Table 2.1, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992,

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Z.1.2 Other Publications.

Z.1.2.1 ACGIH Publications.

American Conference of Governmental Industrial Hygienists, 3640 Park 42 Drive, Cincinnati, OH 45241.

Industrial Ventilation: A Manual of Recommended Practice, 2023.

Z.1.2.2 AIChE Publications.

American Institute of Chemical Engineers, 120 Wall Street, 23rd Floor, New York, NY 10005.

AIChE Center for Chemical Process Safety (CCPS), *Guidance for Writing Effective Operating and Maintenance Procedures*, 1996.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Chemical Process Quantitative Risk Analysis* , October 1999.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Combustible Dust Hazard Analysis*, May 2017.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Consequence Analysis of Chemical Releases,* March 1995.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Developing Quantitative Safety Risk Criteria*, 2009.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Engineering Design for Process Safety,* 2nd edition, 2012.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Hazard Evaluation Procedures*, 3rd edition, 2008.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Investigating Process Safety Incidents*, 2019.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for the Management of Change for Process Safety*, 2008.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Process Safety in Bioprocess Manufacturing Facilities,* November 2010.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Risk Based Process Safety*, 2007.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Safe Automation of Chemical Processes*, 2nd edition, 2016.

AIChE Center for Chemical Process Safety (CCPS), *Guidelines for Safe Handling of Powders and Bulk Solids,* 2004.

AIChE Center for Chemical Process Safety (CCPS), *Inherently Safer Chemical Processes: A Life Cycle Approach,* 3rd edition, 2019.

Britton, L.G., *Avoiding Static Ignition Hazards in Chemical Operations*, AIChE Center for Chemical Process Safety, 1999.

Forbath, T. P. “Sodium Reduction Route Yields Titanium,” *Chemical Engineering Progress*, March 1958.

Powell, R. L. “Chemical Engineering Aspects of Titanium Metal Production,” *Chemical Engineering Progress*, March 1954, pp. 578–581.

~~**Z.1.2.3** AIHA Publications.~~

~~American Industrial Hygiene Association, 3141 Fairview Park Drive, Suite 777, Falls Church, VA 22042.~~

~~ANSI/AIHA Z10, *Occupational Health and Safety Management Systems* , 2012.~~

Z.1.2.3 AMCA Publications.

Air Movement and Control Association International, Inc., 30 West University Drive, Arlington Heights, IL 60004-1893.

AMCA Standard 99, *Standards Handbook,* 2016. (Supersedes AMCA Standard 99-0401)

Z.1.2.4 ASM International Publications.

American Society of Metals, 9639 Kinsman Road, Materials Park, OH 44073-0002.

ASM Handbook, Volume 1: Properties and Selection: Irons, Steels, and High-Performance Alloys, 2017.

ASM Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, 2017.

Z.1.2.5 ASME International Publications.

American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990.

Boiler and Pressure Vessel Code, ~~2023~~ 2025 .

ASME B.31.3, *Process Piping*, ~~2022~~ 2024 .

Z.1.2.6 ASSP Publications.

American Society of Safety Professionals, 520 N. Northwest Highway, Park Ridge, IL 60068.

ANSI/ASSP A10.3, *Safety Requirements for Powder-Actuated Fastening Systems*, 2020.

ANSI/ASSP Z10.0, *Occupational Health and Safety Management Systems* , 2019.

Z.1.2.7 ASTM Publications.

ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D2240, *Standard Test Method for Rubber Property — Durometer Hardness*, 2015, reapproved 2021.

ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*, 2014, reapproved 2021e1.

ASTM D378, *Standard Test Methods for Rubber (Elastomeric) Conveyor Belting, Flat Type*, 2010, reapproved 2016.

ASTM D991, *Standard Test Method for Rubber Property Volume — Resistivity of Electrically Conductive and Antistatic Products* , 1989, repproved 2026.

ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*, ~~2022~~ 2024 .

ASTM E136, *Standard Test Method for Assessing Combustibility of Materials Using a Vertical Tube Furnace at 750°C*, ~~2022~~ 2026 .

ASTM E582, *Standard Test Method for Minimum Ignition Energy and Quenching Distance in Gaseous Mixtures*, 2021.

ASTM E1226, *Standard Test Method for Explosibility of Dust Clouds*, 2019, reapproved 2025 .

ASTM E1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*, 2023.

ASTM E1491, *Standard Test Method for Minimum Autoignition Temperature of Dust Clouds*, 2006, reapproved ~~2019~~ 2025 .

ASTM E1515, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*, 2014, reapproved 2022.

ASTM E2012, *Standard Guide for the Preparation of a Binary Chemical Compatibility Chart*, 2006, reapproved 2020.

ASTM E2019, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*, 2003, reapproved ~~2019~~ 2025 .

ASTM E2021, *Standard Test Method for Hot-Surface Ignition Temperature of Dust Layers*, 2015, reapproved 2023.

ASTM E2079, *Standard Test Methods for Limiting Oxygen (Oxidant) Concentration in Gases and Vapors*, 2019.

ASTM E2456, *Standard Terminology Relating to Nanotechnology*, 2006, reapproved 2020.

ASTM E2931, *Standard Test Method for Limiting Oxygen (Oxidant) Concentration of Combustible Dust Clouds*, 2013, reapproved ~~2019~~ 2025 .

ASTM F955, *Standard Test Method for Evaluating Heat Transfer through Materials for Protective Clothing Upon Contact with Molten Substances*, 2015, reapproved 2021.

ASTM F1002, *Standard Performance Specification for Protective Clothing for Use by Workers Exposed to Specific Molten Substances and Related Thermal Hazards*, 2015, reapproved 2021.

ASTM F1930, *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin* , 2018.

ASTM F2621, *Standard Practice for Evaluating Response Characteristics of Safety Products in an Electric Arc Exposure*, 2022.

Z.1.2.8 Battelle Memorial Institute Publications.

Battelle Memorial Institute, Defense Metals Information Center, 505 King Ave., Columbus, OH 43201.

General Recommendations on Design Features for Titanium and Zirconium Production-Melting Furnaces, 1961.

Z.1.2.9 BSI Publications.

BSI British Standards, 12950 Worldgate Drive, Suite 800, Herndon, VA 20170.

BS EN 1127-1, *Explosive atmospheres, explosion prevention and protection— Basic concepts and methodology*, 2019.

BS EN 14034-1, *Determination of explosion characteristics of dust clouds — Part 1: Determination of the maximum explosion pressure* P_{max} *of dust clouds*, 2004, amended 2011.

BS EN 14034-2, *Determination of explosion characteristics of dust clouds — Part 2: Determination of the maximum rate of explosion pressure rise* $(dP/dt)_{max}$ *of dust clouds*, 2006, amended 2011.

BS EN 14034-3, *Determination of explosion characteristics of dust clouds — Part 3: Determination of the lower explosion limit (LEL) of dust clouds*, 2006, amended 2011.

BS EN 14034-4, *Determination of explosion characteristics of dust clouds — Part 4: Determination of the limiting oxygen concentration (LOC) of dust clouds*, 2004, amended 2011.

BS EN 15188, *Determination of the spontaneous ignition behavior of dust accumulations*, 2020.

BS PD CLC/TR 60079-32-1, *Explosive atmospheres Part 32-1: Electrostatic hazards, guidance,* 2019. (Supersedes BS PD CLC/TR 50404 and BS 5958-1.)

Z.1.2.10 FM Publications.

FM, 270 Central Avenue, Johnston, RI 02919.

FM Property Loss Prevention Data Sheet 1-44, *Damage-Limiting Construction*, ~~January 2023~~ October 2024 .

FM Property Loss Prevention Data Sheet 6-7, *Fluidized Bed Boilers,* January 2021.

FM Property Loss Prevention Data Sheet 6-13, *Waste Fuel-Fired Facilities,* January 2021.

FM Property Loss Prevention Data Sheet 7-10, *Wood Processing and Woodworking Facilities,* May 2010.

FM Property Loss Prevention Data Sheet 7-11, *Conveyors*, ~~January 2024~~ April 2025 .

FM Property Loss Prevention Data Sheet 7-14, *Fire Protection for Chemical Plants*, July 2019.

FM Property Loss Prevention Data Sheet 7-76, ~~*Prevention and Mitigation of Combustible Dust Explosion and Fire,* July 2020~~ *Combustible Dusts* , October 2024 .

FM Property Loss Prevention Data Sheet 7-99, *Heat Transfer Fluid Systems,* January 2022.

Z.1.2.11 ICC Publications.

International Code Council, 500 New Jersey Avenue, NE, 6th Floor, Washington, DC 20001.

International Building Code, 2024 edition.

International Fire Code, 2024 edition.

Z.1.2.12 IEC Publications.

International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland.

IEC 60079-10-2, *Explosive atmospheres — Part 10:2 Classification of areas — Explosive dust atmospheres*, 2015.

ISO/IEC/UL 80079-20-2, *Explosive atmospheres — Part 20-2: Material characteristics — Combustible dusts test methods*, 2016.

IEC 61340-4-4, *Electrostatics — Part 4-4: Standard test methods for specific applications — Electrostatic classification of flexible intermediate bulk containers (FIBC),* 2018.

IEC TS 60079-32-1, *Explosive atmospheres — Part 32-1: Electrostatic hazards, guidance*, 2013.

Z.1.2.13 IFA Publications.

Institute for Occupational Safety and Health of the German Social Accident Insurance, Alte Heerstr. 111, 53757 Sankt Augustin, Germany.

GESTIS-DUST-EX,Combustion and Explosion Characteristics of Dusts (database), February 2001.

Z.1.2.14 ISO Publications.

International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 284, *Conveyor Belts – Electrical Conductivity – Specification and Test Method*, ~~2012~~ 2025 .

ISO 6184-1, *Explosion protection systems — Part 1: Determination of explosion indices of combustible dusts in air*, 1985, confirmed 2021.

ISO 6184-4, *Explosion protection systems — Part 4: Determination of efficiency of explosion suppression systems*, 1985, confirmed 2021.

ISO 8031, *Rubber and plastics hoses and hose assemblies — Determination of electrical resistance and conductivity*, 4th edition, 2020.

Z.1.2.15 National Grain and Feed Association Publications.

National Grain and Feed Association, 1400 Crystal Drive, Suite 260, Arlington, VA 22202.

Dust Explosion Propagation in Simulated Grain Conveyor Galleries, 1983 edition.

Emergency Preplanning and Fire Fighting Manual — A Guide for Grain Elevator Operators and Fire Department Officials, 1987.

Z.1.2.16 NEMA Publications.

ANSI/NEMA 250, *Enclosures for Electrical Equipment*, 2020.

Z.1.2.17 NIBA Publications.

NIBA — The Belting Association, 22 North Carroll Street, Suite 300, Madison, WI 53703.

Technical Note 09, “Static Electricity Considerations,” 2009.

Z.1.2.18 SFPE Publications.

Society of Fire Protection Engineers, 9711 Washingtonian Boulevard, Suite 380, Gaithersburg, MD 20878.

SFPE *Engineering Guide to Fire Risk Assessment*, 2006.

SFPE *Engineering Guide to Performance-Based Fire Protection*, 2nd edition, 2007.

SFPE *Guidelines for Peer Review in the Fire Protection Design Process,* 2009.

SFPE *Handbook of Fire Protection Engineering*, 4th edition, 2008.

SFPE *Handbook of Fire Protection Engineering*, 5th edition, 2016.

SFPE S.01, *Engineering Standard on Calculating Fire Exposures to Structures*, 2011.

SFPE S.02, *Engineering Standard on Calculation Methods to Predict the Thermal Performance of Structural and Fire Resistive Assemblies*, 2015.

Z.1.2.19 UL Publications.

Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ISA-12.12.03/UL 121203, *Portable Electronic Products Suitable for Use in Class I and II, Division 2, Class I, Zone 2 and Class III, Division 1 and 2 Hazardous (Classified) Locations,* 2021.

UL 2011, *Outline of Investigation for Machinery*, 2022.

Z.1.2.20 UN Publications.

United Nations Publications Customer Service, P.O. Box 960, Herndon, VA 20172.

Recommendations for the Transport of Dangerous Goods: Model Regulations — Manual of Tests and Criteria, 2011.

Z.1.2.21 US Bureau of Mines Publications.

US Bureau of Mines, Pittsburgh Research Center, Cochrans Mill Road, Pittsburgh, PA 15236-0070. [Closed in 1996. The National Technical Reports Library has a legacy collection of USBM publications dating 1910–1996.]

RI 3722, "Inflammability and Explosibility of Metal Powders," I. Hartmann, J. Nagy, and H. R. Brown, 1943.

RI 4835, "Explosive Characteristics of Titanium, Zirconium, Thorium, Uranium and Their Hydrides," I. Hartmann, J. Nagy, and M. Jacobsen, 1951.

RI 4879, "Recent Practice at the Bureau of Mines, Boulder City, Nev., Titanium Plant," H.C. Fuller, et al., 1951.

RI 6516, "Explosibility of Metal Powders," M. Jacobsen, A. R. Cooper, and J. Nagy, 1964.

RI 6517, "Application of Computers to Heat Flow and Cost Analysis in Furnace Wall Design," M. J. Lempel, D. Bienstock, and J. H. Field, 1964.

RI 8798, "Thermal and Electrical Ignitability of Dusts."

Z.1.2.22 US Government Publications.

US Government Publishing Office, 731 North Capitol Street, NW, Washington, DC 20401.

DOE Handbook, *Primer on Spontaneous Heating and Pyrophoricity,* DOE-HDBK-1081-1984.

DOT Pipeline and Hazardous Materials Safety Administration, *Emergency Response Guidebook (ERG)*, "Table of Water-Reactive Materials Which Produce Toxic Gases," 2008.

"Hoeganaes Corporation: Gallatin, TN — Metal Dust Flash Fires and Hydrogen Explosion," US Chemical Safety and Hazard Investigation Board, 2012.

Occupational Safety and Health Act of 1970.

OSHA, *Firefighting Precautions at Facilities with Combustible Dust,* 2013.

Title 29, Code of Federal Regulations, Part 1910.38, "Emergency Action Plans."

Title 29, Code of Federal Regulations, Part 1910.119, "Process Safety Management of Highly Hazardous Chemicals."

Title 29, Code of Federal Regulations, Part 1910.146, "Permit-Required Confined Spaces."

Title 29, Code of Federal Regulations, Part 1910.165, "Employee Alarm Systems."

Title 29, Code of Federal Regulations, Part 1910.242(b), "Hand and Portable Powered Tools and Equipment, General."

Title 29, Code of Federal Regulations, Part 1910.272, "Grain Handling Facilities."

Title 30, Code of Federal Regulations, Part 18, Section 12.18.65, "Electric Motor-Driven Mine Equipment and Accessories."

Title 30, Code of Federal Regulations, Part 36, "Approved Requirements for Permissible Mobile Diesel-Powered Transportation Equipment."

Title 49, Code of Federal Regulations, Parts 100–199, "Pipeline and Hazardous Materials Safety Administration, Department of Transportation."

Title 49, Code of Federal Regulations, Parts 171–178, "Hazardous Materials Regulations."

Z.1.2.23 Other Publications.

Amyotte, P.R., Pegg, M.J., and Khan F.I., “Application of inherent safety principles to dust explosion prevention and mitigation,” *Process Safety and Environmental Protection* 87, pp. 35–39, 2009.

Babrauskas, V., *Ignition Handbook Database*, Fire Science Publishers, Society of Fire Protection Engineers (SFPE), 2003.

Boilard, Simon P., “Explosibility of micron- and nanosize titanium powders,” *Journal of Loss Prevention in the Process Industries*, vol. 26, pp. 1–9, 2013.

Bouillard, J., A. Vignes, O. Dufaud, L. Perrin, and D. Thomas. “Ignition and Explosion Risks of Nanopowders,” *Journal of Hazardous Materials* 181: 873–880, 2010.

Bowes, P.C., *Self-Heating: Evaluating and Controlling the Hazards,* Elsevier, 1984.

Cashdollar, Kenneth, and Zlochower, Isaac. “Explosion Temperatures and Pressures of Metals and Other Elemental Dust Clouds,” *J. Loss Prevention in the Process Industries*, vol. 20, 2007.

Dastidar, A.G., P.R. Amyotte, J. Going, and K. Chatrathi, “Flammability Limits of Dusts: Minimum Inerting Concentrations," *Process Safety Progress*, vol. 18, No. 1, Spring 1999.

Drysdale, Dougal, *Introduction to Fire Dynamics*, 2nd edition, pp. 77, 129, 148–149, John Wiley & Sons, New York, NY, 2011.

Ebadat, V., and J. C. Mulligan, “Testing the Suitability of FIBCs for Use in Flammable Atmospheres,” Paper 10a, 30th Annual Loss Prevention Symposium, AIChE, 1996 Spring National Meeting, New Orleans, LA, February 26–28, 1996.

Eckhoff, R., *Dust Explosions in the Process Industries*, 2003.

Eisner, H. S., “Aluminum and the Gas Ignition Risk,” *The Engineer*, London, Feb. 17, 1967.

Gibson et al., “Fire Hazards in Chemical Plants from Friction Sparks Involving the Thermite Reaction,” Industrial Chemists Engineering Symposium Series, No. 25, London, 1968.

Glor, M., *Electrostatic Hazards in Powder Handling*, Research Studies Press Ltd., 1988.

Janés, A., Marlair, G., Carson, D., Chaineaux, J., “Towards the improvement of UN N.5 test method for the characterization of substances which in contact with water emit flammable gases,” *Journal of Loss Prevention in the Process Industries*, vol. 25. pp. 524–534, 2012.

Jones, J.C., “Recent Developments and Improvements in Test Methods for Propensity Towards Spontaneous Heating,” *Fire and Materials*, vol. 23, issue 5, pp. 239–243, September/ October 1999.

Krietsch et al., “Explosion behaviour of metallic nano powders,” *Journal of Loss Prevention in the Process Industries*, vol. 36, pp. 237–243, 2015.

Krock, R., et al., “OSHA’s Combustible Dust National Emphasis Program and Combustibility Characteristics Testing of PVC Resins and PVC Dusts,” SPE ANTEC, April 2012.

Larrañaga, Michael D., Lewis Sr., Richard J, and Lewis, Robert A., *Hawley’s Condensed Chemical Dictionary*, sixteenth edition, 2016.

Lerner, M., Vorozhtsov, A., Guseinov, Sh., and Storozhenko, P., “Chapter 4: Metal Nanopowders Production,” *Metal Nanopowders: Production, Characterization, and Energetic Application*, John Wiley & Sons, Inc., 2014.

Liz-Marzan, L.M., “Nanometals: Formation and color,” *Materials Today*, February 2004.

Mäkelä, Jyrki M., et al., “Nanoparticle Deposition from Liquid Flame Spray onto moving Roll-to-Roll Paperboard Material,” *Aerosol Science and Technology*, vol. 45, pp. 827–837, March 2011.

Miron, Y. and Lazzara, C. P. “Hot Surface Ignition Temperatures of Dust Layers,” *Fire and Materials,* September 1998.

Mittal, “Limiting oxygen concentration for coal dusts for explosion hazard analysis and safety,” *Journal of Loss Prevention in the Process Industries*, vol. 26, Issue 6, pp. 1106–1112, November 2013.

Mittal, “Explosion characteristics of micron- and nano-size magnesium powders,” *Journal of*

Loss Prevention in the Process Industries, vol. 27, pp. 55–64, January 2014.

Mosher, A. D., McGuffie, S. M., and Martens, D.H., *Molten Sulfur Fire Sealing Steam Requirements*, Brimstone Sulfur Symposium, Vail CO., September 2015.

Nazarenko, O., et al., “Chapter 3: Electroexplosive Nanometals,” *Metal Nanopowders: Production, Characterization, and Energetic Application*, John Wiley & Sons, Inc., 2014.

Persson, Henry, *Silo Fires: Fire extinguishing and preventive and preparatory measures*, Swedish Civil Contingencies Agency, July 2013.

Pineau, J., and Ronchail, G. “Propagation of Dust Explosions in Ducts,” Proceedings of the Symposium on the Control and Prevention of Dust Explosions, Basel, 1982.

Sahiner, N., “Soft and flexible hydrogel templates of different sizes and various functionalities for metal nanoparticle preparation and their use in catalysis,” *Progress in Polymer Science*, vol. 38, 2013.

Schrofel, A., et al., “Applications of biosynthesized metallic nanoparticles: a review,” Acta Biomaterialia, vol. 10, no. 10, pp 4023–42, Oct. 2014.

Taveau, Jerome, “Dust explosion propagation and isolation,” *Journal of Loss Prevention in the Process Industries*, vol. 48, pp. 320–330, 2017.

Taveau, J., et al., “Igniter-induced hybrids in the 20-L sphere,” *Journal of Loss Prevention in the Process Industries*, vol. 49, part B, pp. 348–356, September 2017.

Ural, Erdem, Fire Protection Research Foundation report, “Towards Estimating Entrainment Fraction for Dust Layers,” June 2011.

VDI Guidelines 2263, Part 1, *Test Methods for the Determinations of Safety Characteristics Dusts*, 2005.

VDI Guidelines 3673, *Pressure Release of Dust Explosions*, 2002.

Wu, et al., “Flame phenomena in nanogrinding process for titanium and iron,” *Journal of Loss Prevention in the Process Industries*, vol. 27, pp 114–118, 2014.

Wu, Hong-Chun, Yung-Chih Kuo, Yuan-heng Wang, Chia-Wei Wu, and Hsiao-Chi Hsiao, “Study on Safe Air Transporting Velocity of Nanograde Aluminum, Iron, and Titanium.” *Journal of Loss Prevention in the Process Industries* 23: 308–311, 2010.

Zalosh, R. and Greenfield, W., “A probabilistic approach to dust explosion propagation hazard evaluations,” Tenth International Symposium on Hazards, Prevention, and Mitigation of Industrial Explosions, Bergen, Norway, June 10–14, 2014.

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Z.3 References for Extracts in Informational Sections.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* 2023 edition.

NFPA 70®, *National Electrical Code*®, ~~2023~~ 2026 edition.

NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas,* 2024 edition.

NFPA 2113, *Standard on the Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* 2025 edition.

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