NFPA 660-2025 Edition
Standard for Combustible Dusts
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1. Delete and replace Annex V to read as follows:

~~Annex V Guide for Computing Thermal Dose to Personnel from Flash Fires and Building Compartment Deflagrations (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.~~

Annex V Guide for Computing Thermal Dose to Personnel 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 protection of occupants from that hazard. NFPA 2113 is used for the selection and use of personnel protection garments to protect occupants from the effects of a flash fire resulting from a deflagration. NFPA 2113 requires that the facility operator perform a workplace hazard assessment to identify where within the facility the occupants should be equipped with protective clothing. This annex provides guidance on how one might execute the hazard assessment for facilities covered under the scope of this standard.

The ignition of ordinary clothing made of cotton and polyester fabrics has been reported when it is exposed to radiant flux on the order of 50 kW/m^2, and it attains temperatures of 200°C to 300°C. [1, 2] Relatively brief exposures to 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 [2] One means of protecting occupants is the use of flame-resistant garments (FRG) designed in accordance with NFPA 2112 and used in accordance with NFPA 2113. However, the use of FRG is not a panacea; there are limits to its use, and the facility operator should ensure that it is not considered as a safeguard for scenarios where the thermal flux will result in an unacceptable injury to an occupant or exceeds the capabilities of the FRG. Notwithstanding the finite thermal protective capabilities of FGR, it still might be wise to use it as a safeguard, as long as it is recognized, because it won’t be adequate on its own.

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

V.2.1 Hazard Management Strategy Development Concept. The first step in assessing the workplace hazard management is establishing clear objectives for personnel safety. Once a performance objective has been established, a qualitative or quantitative 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, and the thermal fluxes on employee(s) under worst-case circumstances are computed. These thermal fluxes are compared to the performance criteria associated with the proposed personnel protection to verify that the protection objectives will be achieved.

V.2.1.1 Personnel Safety Objective. The first step in designing a personnel safety system is defining the minimum level of personnel injury that exceeds what the facility is willing to tolerate. This establishes a personnel safety objective.

For example, a facility operator might adopt a personnel safety objective of no employee suffering a permanently life-altering injury at work. In this case, the objective would encompass injuries such as permanent eye injury, hearing loss, amputations, spinal cord injuries, and so forth. But this objective would not address injuries such as broken bones or lacerations requiring stitches as these later examples are generally expected to heal. While the personnel injuries in this second category are extremely undesirable and every effort will be made to prevent them, such injuries do not exceed the limit of what can be tolerated for the particular site. Since extensive third degree burns usually result in the permanent loss of skin and can cause other complications such as infection and loss of blood flow, they are usually considered permanently life-altering and would fall outside the tolerable limit in this example.

In other cases, the injury prevention objective described in the previous paragraph is unattainable due to the severity of the hazard. In this case the facility must accept an objective that allows for more severe injury. As an example, such a facility might adopt the objective of prevention of loss of life. In this case, permanent injury, while again extremely undesirable, is within the limit of what can be tolerated as long as fatality is prevented.

V.2.1.2 Performance Criteria. Once a performance objective has been established, a qualitative or quantitative criterion can be derived. In the case of burn injury hazard management, a qualitative criterion might be the prevention of ignition of occupant's clothing. A quantitative criterion might be the thermal flux necessary to produce the injury threshold established in the objective policy statement.

The thermal flux (heat flow into the target) can be via radiation, convection, or conduction as well as the sum of more than one of the individual thermal flow vectors depending upon the fire scenario. Since this annex addresses primarily when FRG should be used and when it should not be considered sufficient, it addresses only the first two. Protection against conductive heat transfer is generally achieved with physical barriers to prevent contact or insulating protective garments such as gloves when intentional contact is anticipated. 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.2.1.3 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 focused on the thermal exposure of employees to flash fires involving an unconfined 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 forced out of the ullage volume of a mixer during the addition of a combustible resin. This scenario is illustrated conceptually in Figure V.2.1.3(a).

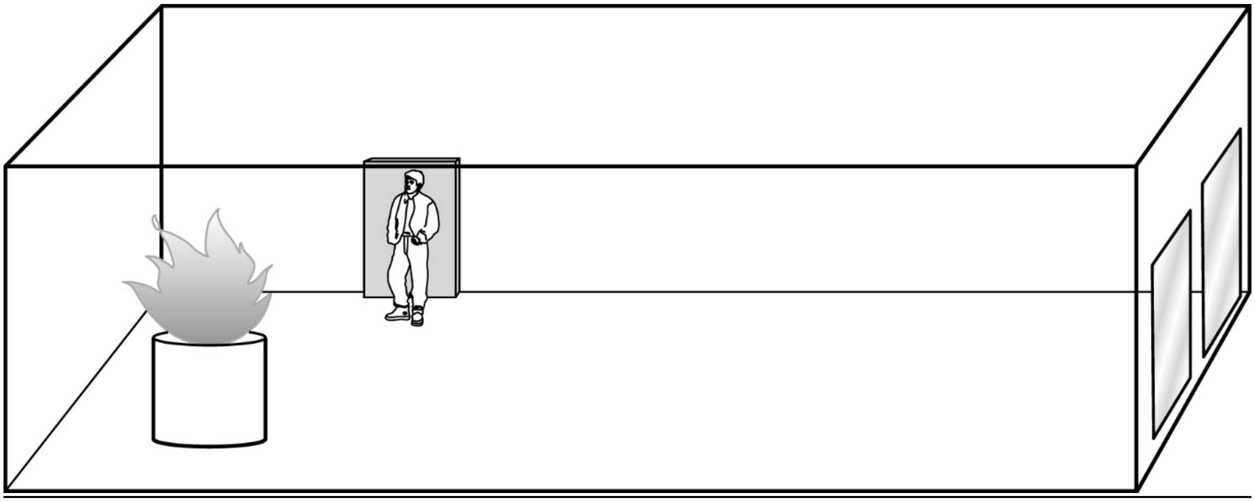

Figure V.2.1.3(a) The "Inherently Limited Deflagration" Scenario.

As long as there is no accumulated fugitive dust in the building compartment that can be suspended, entrained, and ignited by the initial deflagration, the flash fire is inherently limited by the quantity of fuel ejected from the mixer. The deflagration flame extension into the building compartment interior and its impact on occupants can be predicted using relations included in V.2.2 and V.2.3.

The second scenario is where an initial deflagration occurs in a building compartment where fugitive combustible dust has accumulated on interior building compartment surfaces such as upward-facing ledges, beam flanges and tops of equipment enclosures, pipes, ducts, electrical conduits, and so forth. This accumulated dust load can be dislodged and dispersed by the pressure pulse from an initiating event, and ignition of the suspended dust would result in a deflagration flame front propagating across the interior volume of the building compartment. The building compartment deflagration scenario is illustrated conceptually in Figure V.2.1.3(b).

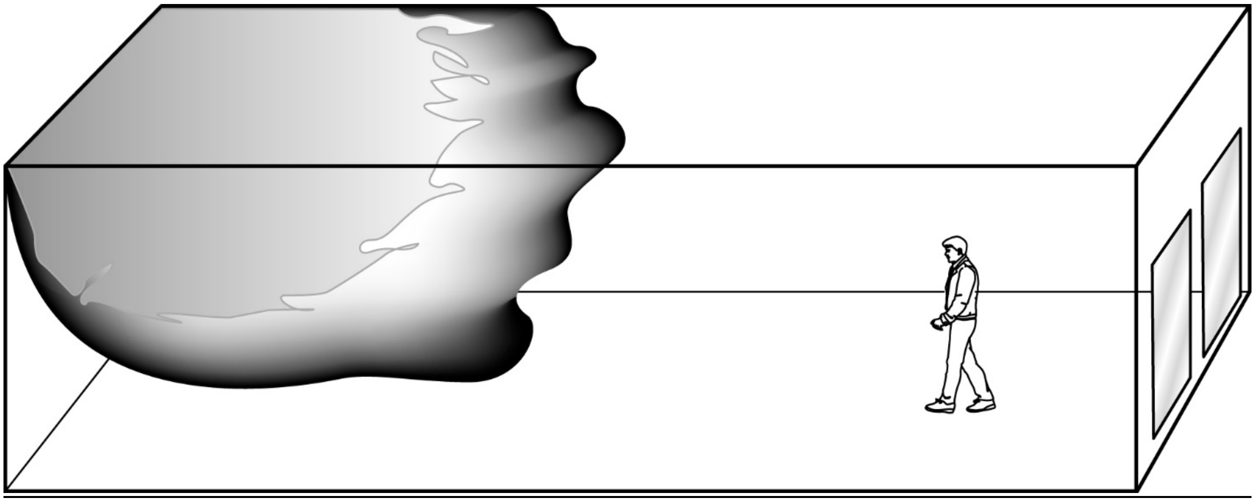

Figure V.2.1.3(b) The "Building Compartment Deflagration" Scenario.

As the deflagration flame front propagates through the dust suspension, 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 intensity impinging on the occupant. Furthermore, the flame front has a supply of fuel that provides the requisite conditions to continue the combustion as the burning cloud spreads across the compartment interior. Thus, the flame front will eventually impinge upon and potentially engulf the occupant.

The distinction between impingement and engulfment can be important. Impingement is generally taken to mean that the flame front reaches the nearest surface of the target and can provide piloted ignition to that surface. Engulfment implies that the target is enveloped in flaming combustion gases. The heat flux into the target is expected to be far greater when the target is engulfed, resulting in more extensive and severe burn injuries. Furthermore, when the target is a person, engulfment implies pulmonary injury and searing of the airway from the inhalation of hot gas. These two effects substantially increase the probability of fatality.

At the moment of flame impingement or engulfment, convective heat transfer is added to the radiant heat transfer and the thermal flux impinging on the occupant increases enormously. The relations available to compute convective heat transfer are far more complex than those for radiant transfer, making predictive calculations much more difficult. More importantly, depending on the deflagration scenario and the type of FRG being worn, flame front engulfment can exceed the capabilities of FRG and flame engulfment is often fatal.

The test method used by NFPA 2112, ASTM F1930, *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin,* uses propane burners that produce a combined radiant and convective heat flux. The thermal dose acceptance criteria for FRG designed and tested in accordance with NFPA 2112 is 252 kJ/m^2.[3] This exceeds the following thermal dose criteria often used for personnel injury thresholds to bare skin: [4]

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

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.

V.2.1.4 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. For those cases where flame impingement is not contemplated in the flash fire scenario, the thermal flux is limited to the radiant flux. If flame impingement cannot be precluded, FRG is needed to prevent the immediate ignition of the occupant's clothing and likely fatality.

If a flash fire resulting from a building compartment deflagration fueled by accumulated fugitive dust is possible, FRG should not be relied upon to achieve a personnel protection objective. It can be useful for reducing the severity and probability of injuries exceeding the protection objectives, but there is a 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.

V.2.2 Estimating Radiant Flux Hazard. There are a number of computational methods for predicting the radiant flux impinging on a target as a function of a given fire geometry. [5]

These calculations have been developed primarily for hydrocarbon pool fires and for flammable gas and vapor cloud fires. Where commonly encountered particulates like agricultural, forest, animal-derived, and plastic products are concerned, the combustion chemistries are sufficiently similar that it is unlikely that the use of those calculations to model a dust deflagration introduces significant errors. However, this has not been validated yet.[6] Metallic particulates burn with sufficiently different chemistries that yield very different combustion products and often with far greater heat release per unit of fuel mass. When metallic particulates are involved, corrections should be made to the computational models before use.

The radiant flux intensity (kW/m^2) impinging on the target can be computed at the worst-case (minimum) separation distance from the scenario deflagration flame. The radiant emissions from a deflagration flame extend spherically from the flame epicenter, radiating outward as straight-line emissions, as shown in Figure V.2.2.

For a hypothetical point-source radiator, the incident radiant flux, *q*, impinging on a target can be predicted using the relation in Equation V.2.2a. [5]

$$q'' = \tau X_r \left(Q / 4\pi L^2 \right) \cos\Theta \qquad \textbf{[V.2.2a]}$$

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

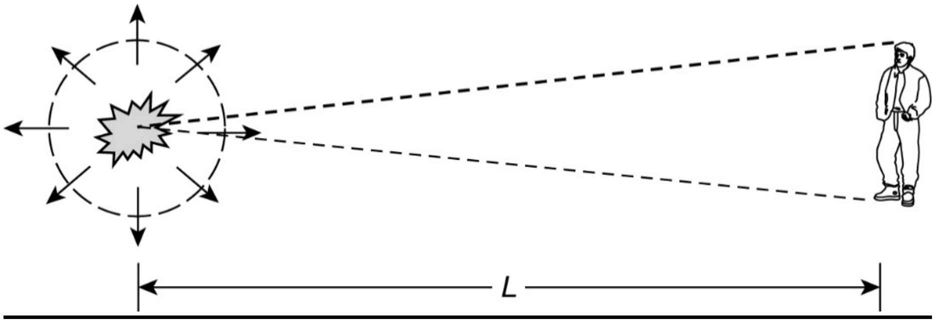

Figure V.2.2 The Radiant Emission from a Deflagration.

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 $\cos \Theta = 1$. Secondly, we assume a worst-case circumstance with no atmospheric absorbance in the transmission path, making $\tau = 1$.

A bounding value estimate for the radiant flux 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, and the net heat of combustion of the fuel, ΔH_c. Then Equation V.2.2 can be used to compute an estimate of the radiant intensity impinging upon a target (occupant) at known separation distance.

The radiative fraction, X_r, is reported to have values from 0.1 to 0.4. [5] Customarily, fire protection engineers use a radiant fraction of 30 percent to 35 percent for diffusion flames. There is very limited research investigating a potential different radiant fraction for deflagration flames involving combustible dusts.

As stated previously, this radiative fraction is not suitable for metallic particulates. While it can be tempting to use flame temperature and an estimated emissivity to derive a radiant fraction for metallic particulates, caution should be exercised. The radiant emissions from a flame are influenced by the chemical composition of the combustion products. The combustion products from the combustion of metallic particulates are metallic oxides and should not be expected to exhibit similar spectra to the combustion products of more common, carbon-containing materials found in plastics, agricultural, paper, and forest-products industries.

To estimate the radiant emission from a given deflagration scenario, an estimate of the heat release from the deflagration must be developed and calculated forward to the radiant intensity impinging upon the contemplated target individual. For combustible dust processing facilities this is usually derived from the maximum anticipated dust suspension cloud volume at the maximum, 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. However, 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 locus of the modeled dust suspension cloud that could extend the combustion zone beyond the volume considered in the scenario.

It is important to note that the previous calculation using a point source model is applicable only in scenarios where the separation distance (L) is much greater than the diameter of the fireball. At closer distances, the point source method has been shown to systematically under-predict heat fluxes to a target. As a general guideline, the point source model should not be applied where the estimated heat fluxes are below 5 kW/m^2. [7]

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 us to base the calculations on the radiating area of the flame and a radiant 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 with an average emissive power intensity per unit area. An emissive power per unit area of 350 kW/m^2 is widely used. [5] The value of 200 kW/m^2 to 350 kW/m^2 has been suggested for BLEVE deflagrations. [8] However, this value is only appropriate for hydrocarbon-based fuels such as agricultural products, forest-products, paper, plastics, and similar organic compounds. This value is not appropriate for metallic particulates.

The deflagration flame is usually assumed to have an average surface emissive power, E, (kW/m^2). The radiant power impinging on the target is generally expressed as shown in Equation V.2.2b. [5]

$$q'' = \tau E F \qquad \textbf{[V.2.2b]}$$

where:

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

τ = transmissivity of medium, air (percent)

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

F = geometric configuration factor

Assigning the value of 1 to τ for clear air and surface emissivity of 350 kW/m^2, Equation V.2.2 becomes Equation V.2.2c.

$$q = 350F \qquad \textbf{[V.2.2c]}$$

where:

q = incident radiant heat flux (kW/m^2)

F = configuration factor between the fireball and target (value of 0 to 1)

In Equation 2.2c, the configuration factor (F) becomes an important component of the calculation. For a detailed analysis, this can be calculated as a function of the expected fireball dimensions and separation distance to a target using the method presented by Beyler. [7].

Using one of the methods above, one can compute the radiant flux intensity impinging on the occupant. The calculated radiant flux intensity is compared to the flux intensity associated with the level of tolerable injury. If the flux intensity at the occupant location exceeds the flux intensity sufficient to cause third degree burns on skin that is unprotected by clothing for sufficient time, third degree burns are expected to result. Also, if the flux intensity at the occupant location exceeds the flux intensity sufficient to ignite clothing, then third degree burns are expected to occur due to exposure to burning clothing. In this second case the personnel injury limitation objective criterion has been exceeded and fatality is likely. [2]

V.2.3 Estimating Deflagration Flame Impingement Hazard. The radiant flux intensity estimate above is based upon modeling the deflagration as occurring instantaneously 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 intensity on a target at a defined separation distance. The heat release is modeled as uniformly distributed throughout the dust suspension volume instantaneously and as an optically dense radiator having a circular radiating area. The assumption that there is no flame impingement must be confirmed.

To obtain a bounding-value estimate for the distance an igniting flame will extend from a deflagration, 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 Universal Gas Law. The flame temperature can be 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.2.3a.

$$C_6H_{10}O_5 + 6\ O_2 \Rightarrow 6\ CO_2 + 5\ H_2O + \text{Heat} \qquad \textbf{[V.2.3a]}$$

Normalizing this stoichiometric equation for 1.0 m^3 of air yields Equation V.2.3b.

$$1.54\ C_6H_{10}O_5 + 9.24\ O_2 + 34.6\ N_2 \Rightarrow 9.24\ CO_2 + 7.7\ H_2O + 34.6\ N_2 + \text{Heat} \qquad \textbf{[V.2.3b]}$$

In addition to the 21 percent volumetric expansion due to the increase in the number of moles of gas in the combustion products there is the liberated heat that will cause the combustion products gas to expand. [9]

$$(470\ \text{kJ/mole}\ O_2)(9.24\ \text{mole}\ O_2) = 4{,}343\ \text{kJ Heat} \qquad \textbf{[V.2.3c]}$$

This heat is liberated into the combustion product gas. The resulting temperature of the gas can be computed using Equation V.2.3d.

$$\Delta T = \Delta H / mc_p \quad \textbf{[V.2.3d]}$$

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.2.3e.

$$\Delta T = \Delta H / \left(m_{CO_2} c_{CO_2} + m_{H_2O} c_{H_2O} + m_{N_2} c_{N_2} + m_{Ar} c_{Ar} \right) \quad \textbf{[V.2.3e]}$$

Using the values in Table V.2.3 leads to a computed temperature increase for the reaction normalized to 1.0 m^3 in volume. [10]

Table V.2.3 Gas Properties

Gas	CO_2	H_2O	N_2	Ar
Mass, g/m^3	401	164	966	16.2
c_p @ 1200 °K, j/g°K	1.28	2.42	1.21	0.312

$$\Delta T = 2083.47°K \quad \textbf{[V.2.3f]}$$

If the reaction occurred at 300°K ambient temperature, deflagration flame temperature is estimated to be approximately 2,383°K. This estimate assumes complete, stoichiometric combustion and does not take into account endothermic pyrolytic processes. This combustion temperature is derived from the chemical equation of the combustion of starch. This temperature cannot be used where the fuel is a metallic particulate.

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 Universal Gas Law relation.

$$P_1 V_1 / nRT_1 = P_2 V_2 / nRT_2 \quad \textbf{[V.2.3g]}$$

In Equation V.2.3g, 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 objects.

Since the ignition of ordinary street clothing made of cotton and polyester fabrics has been reported when exposed to radiant flux on the order of 50 kW/m^2 and attain temperatures of 200°C to 300°C (473°K to 573°K) these criteria establish the minimum separation distance between the initial, pre-ignition dust suspension and the target personnel when the ignition of clothing by deflagration flame impingement is the safety criterion. [1, 2]

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. Since diameter is proportional to the cube root of the volume, the deflagration flame would be expected to lose the ability to ignite clothing once the diameter of the gas volume had increased by a factor of 1.7 to 1.6. As long as personnel are reliably prevented from being closer to the surface of the deflagration flame than 1.6 times, the initial dust cloud diameter the deflagration product gases would not be expected to ignite clothing. This value is for the carbon-containing fuels similar to starch. It is not applicable to metallic particulate deflagrations.

The temperature exposure limits for exposed skin are expected to be much lower. The relations reported are all for radiant flux not for convective flows. [5] Normal skin temperature is 32.5°C. [4] As skin temperature increases above this threshold, the damage increases logarithmically with temperature above approximately 44°C. [4] The damage is proportional to the temperature and time of exposure. At a tissue temperature of 72°C, damage is reported to be “instantaneous”. One can only conclude that sort-duration convective exposure to a deflagration flame will result in third degree burn injury.

If the safety criterion is the prevention of second degree burns on exposed skin, the separation criteria should be calculated using a lower temperature for T_2. The response of the skin to thermal flux is dependent on the energy influx, not temperature. Temperature difference results in heat flow from the hotter mass to the cooler mass. To predict burn injury to exposed skin from convective heat transfer, the gas temperature, velocity, and a number of parameters related to the skin must be quantified. Relations for performing this degree of analysis is presented in the SFPE *Handbook of Fire Protection Engineering*. [5]

Remain mindful that any calculation of deflagration flame extension is predicated on the assumption that there are no dust accumulations present in the building compartment that can become entrained and ignite, thereby adding fuel and extending the flame volume beyond the initial deflagration.

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 experience unbearable 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. [4, 5] This establishes a lower bound, beneath which no exposure limitation is needed.

A relation has been developed to predict the occurrence of second degree burns (skin blister formation). [5] 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 relation below for second degree burns can be used as a bounding-value estimate for the onset of third degree burn injury hazard. [5]

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

where:

t_B = time to skin blister (sec)

$\dot{q}''$ = incident thermal radiant 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, $\dot{q}''$. [5]

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 in the facility. 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 and attained temperatures of 200°C to 300°C, could be used.

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.2.2, and the personnel protection objective can be achieved using separation distance. However, if there is entrainable, accumulated fugitive dust in the building compartment, the deflagration flame volume ceases to be inherently unlimited and separation cannot be relied upon to manage the hazard to personnel. FRG will be needed.

For those cases where the flash fire flame is expected to impinge on one or more occupants, there will be no alternative to relying on FRG. This makes it necessary to quantify the circumstances where flame impingement is expected.

V.2.5 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." [11]

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.

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." [3] NFPA 2113 uses a performance criterion of a thermal dose of 252 kJ/m^2 (84 kW/m^2 for 3.0 seconds) applied to the garment. [3] 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 full body acceptance test, 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*. [11]

FRG is tested in accordance with ASTM F1930 *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin*. [12] The test uses multiple propane burners with flame adjusted to produce a yellow-to-red flame. [13] 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. [13] 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. [13]

The model computes the rate of increase of burn injury factor, dΩ/dt, from the relation in Equation V.2.5a, [13]

$$d\Omega / dt = P \, \exp(-\Delta E/RT) \qquad \textbf{[V.2.5a]}$$

where:

$d\Omega/dt$ = rate of increase in the burn injury factor, Ω, per unit time
T = epidermal skin temperature, °K
R = universal 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.2.5b. [13]

$$\Omega = \int_0^t P \, \exp(-\Delta E / RT) \, dt \qquad \textbf{[V.2.5b]}$$

Second degree burn injury is predicted when the magnitude of $\Omega \le 1.0$ at the dermis/epidermis interface depth and third degree burns are predicted for magnitudes of $\Omega \ge 1.0$ 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. [13] The acceptance criterion is less than 50 percent of the body surface receiving second or third degree burn injury. [11] 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,* 2nd edition, predicts a 50 percent probability of fatality for a thermal flux of 85.2 kW/m^2 for an exposure time of 10 seconds. [8] This value is close to the 84 kW/m^2 thermal flux referenced in A.4.3 of NFPA 2113, and the 10 second exposure duration is of the same order of magnitude as the 3 second duration in NFPA 2113. 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 a 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.2.5c:

$$Y = k_1 + k_2 \ln V \qquad \textbf{[V.2.5c]}$$

The probits (probability units) are converted into percentages using a table. [8] 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. [8]

No quantitative relation is provided for occupants equipped with FRG.

V.3 Hazard Management Strategy Development.

V.3.1 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.3.2 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.

V.3.3 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 above 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 is required.

V.3.4 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.3.4.1 If the calculated radiant flux exceeds the criteria for personnel injury prevention, affected employees should be equipped with FRG designed in accordance with NFPA 2112 and used in accordance with NFPA 2113.

V.3.4.2 Protection should be provided for the body as well as the head, face, and hands.

V.3.4.3 Values for various criteria for unprotected occupants are as follows: [3, 4]

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

V.3.5 The maximum deflagration flame extension distance should be computed for each flash fire scenario.

V.3.5.1 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.

V.3.5.2 Protection should be provided for the body as well as the head, face, and hands.

V.3.5.3 Flame impingement is expected to lead to the ignition of ordinary clothing. Clothing ignition is expected to lead to severe third degree burns and fatality. [2]

V.3.6 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.

V.4 References.

(1) Babrauskas, Vytenis, PhD, *The Ignition Handbook*, pp. 816, 822, Fire Science Publishers, Issaquah, WA, 2003.

(2) TNO The Netherlands Organization of Applied Scientific Research, *Methods for the Determination of Possible Damage*, "TNO Green Book," pp. 8, 12, 25, Table 2.1, CPR 16E, Director General of Labor, The Hague, The Netherlands, 1992.

(3) 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*, Section A.4.3, National Fire Protection Association, Quincy, MA, 2025.

(4) The SFPE Task Group on Engineering Practices, *Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation*, pp. 7, 8, 18, Society of Fire Protection Engineers, Bethesda, MD, 2000.

(5) Hurley, Morgan, P.E., FSFPE, Editor-in-Chief, *The SFPE Handbook of Fire Protection Engineering*, 5th edition, Chapters 66, 67, 68, pp. 2654, 2655, 2705, 2720, 2722, 2723, Springer Science+Business Media, New York, 2016.

(6) O'Hern, Sean C., Stern, Michael C., Vickery, James, Anderson, David M., Ibarreta, Alfonso, Myers, Timothy J., "Impact of Dust-fueled Flash Fires on Personal Protective Equipment Fabrics," 12th International Symposium on Hazards, Prevention and Mitigation of Industrial Explosions, 2018.

(7) Beyler, C., "Fire Hazard Calculations for Large, Open Hydrocarbon Fires," *The SFPE Handbook of Fire Protection Engineering*, 5th edition, Chapter 66, Hurley. M. editor-in-chief, Springer, New York, NY, 2016.

(8) CCPS, *Guidelines for Chemical Process Quantitative Risk Analysis*, 2nd edition, pp. 209, 246, 247, 270, Center for Chemical Process Safety, American Institute of Chemical Engineers, New York, NY, 2000.

(9) Eckhoff, Rolf K., *Dust Explosions in the Process Industries*, 3rd edition, p. 6, Gulf Professional Publishing, Elsevier, Burlington, MA, 2003.

(10) https://www.engineeringtoolbox.com/html.

(11) NFPA 2112, *Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire,* Sections 1.2.1, 7.1.5, 8.5.6.1, National Fire Protection Association, Quincy, MA, 2023.

(12) 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.

(13) ASTM F1930, *Standard Test Method for Evaluation of Flame Resistant Clothing for Protection Against Flash Fire Simulations Using an Instrumented Manikin*, Sections 6.2.2,

6.5.3.1, 6.7.3.1, 13.5, X1.4, X1.5, ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, 2018.

Substantiation: In order to prevent facility operators from relying on FRG without substantiating that it can achieve the life-safety objectives Section 8.6.1 was added. The TC recognized that guidance on how to fulfill the requirement was needed. Text was developed and added at the second revision meeting. Subsequently, errors were found and the Correlating Committee deleted the erroneous text. The proposed TIA text corrects the errors and expands the guidance, providing a more complete presentation of the methodology. Without this Annex material users of NFPA 660 will be unable to comply with the life-safety requirement in Section 8.6.

Emergency Nature: The standard contains an error or an omission that was overlooked during the regular revision process. The proposed TIA intends to offer to the public a benefit that would lessen a recognized (known) hazard or ameliorate a continuing dangerous condition or situation.

The proposed standard includes a requirement to perform a workplace hazard assessment but did not include information on how to fulfill the requirement. The proposed TIA text provides the user with the means to comply with the requirement.

Anyone may submit a comment by the closing date indicated above. Please identify the TIA number, state whether you SUPPORT or OPPOSE the TIA along with your comment, and forward to the Secretary, Standards Council. SUBMIT A COMMENT