

5.10. Solid Fires

While solid fires generally do not have the same impact as flammable material fires in process units, the hazards from solids are important in several respects. Class A materials may be the source of ignition for hazards having a greater combustible loading or posing a greater threat in terms of impact and Class A or D solids may pose a threat due to inherent reactivity or use in a process. For more information on solid fires, refer to *SFPE Handbook* (Beyer, 2002). Radiant heat from solid fires can be calculated similarly to that of pool fires.

5.11. Fire Impact to Personnel, Structures, and Equipment

Once the fire characteristics are calculated, an assessment of the impact of the fire needs to be completed. Fires produce four major outputs: gases, flame, heat, and smoke. The materials involved in the fire will determine the combination of these four outputs. For example, crude oil will produce a very dark thick smoke cloud, and ethylene does not produce much smoke, but does have a very large flame.

The outputs can create consequences to personnel, structures, and equipment. There are different approaches for assessing consequences. Criteria can be developed that will allow the analyst to compare the results of the calculations to predetermined criteria. The results either meet or exceed the criteria. These criteria can be established based on a conservative approach of assuming a steady-state condition. Another approach is the use of more sophisticated heat transfer techniques, where a time-dependent onset of critical criteria is modeled.

Data and procedures presented in this section can be used in either approach. Time-independent approximations of failure criteria are presented to provide first-order estimates of fire consequences. Time-dependent criteria are also presented where specific scenarios warrant more detailed analysis. Most of the thermal criteria is presented in terms of heat flux, although some temperature criteria are also presented. A conservative methodology is presented to translate heat flux from a fire to surface temperature on a material target.

5.11.1. Impact to Personnel

5.11.1.1. Thermal Radiation

When there is a line-of-sight between a person and the flame, the main impact is thermal radiation. The primary potential effects of thermal radiation are:

- Burns to exposed skin.
- Ignition or melting of clothing.

Burns are classified in increasing degrees of severity:

- *First degree*—superficial burns giving a red, dry skin (similar to mild sunburn).
- *Second degree*—burns more than 0.1 mm deep, affecting the epidermis and forming blisters.
- *Third degree*—burns more than 2 mm deep, affecting the dermis and nerve endings, resulting in a dry skin that has no feeling (major blistering).

The time to damage human skin increases logarithmically with the increase in skin temperature. Skin damage begins at about 45°C (113°F) and becomes virtually instantaneous at 72°C (162°F). Complex methods involving the use of thermal skin property are detailed in the literature (SFPE, 2000).

Figure 5-16 (SFPE, 2002) shows a method for predicting first and second degree burns based on heat flux and time. By knowing the exposure flux, one can predict the time to injury. No safety factor is included in this calculation; the estimate is for bare skin, unprotected by clothing.

Other personnel impact criteria are reported in the literature. Table 5-5 reports on data from several sources.

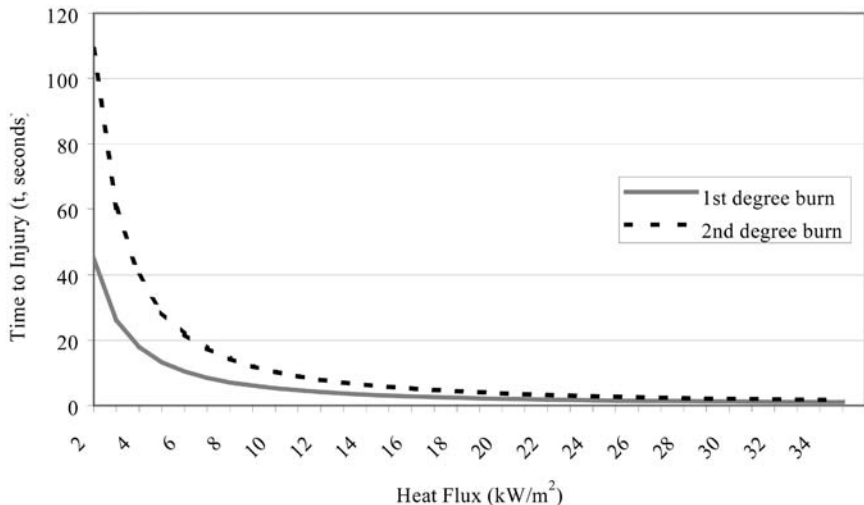


Figure 5-16. Prediction of First- and Second-Degree Burns

Table 5-5*Estimated Effects of Heat on Personnel*

Incident Flux (kW/m ²)	Impact
37.5	100% lethality in 1 minute (Barry, 2002)
25	1% lethality in 10 seconds (Barry, 2002)
15.8	100% lethality in 1 minute, significant injury in 10 seconds (Barry, 2002)
12.5	1% lethality in 1 minute; first degree burns in 10 seconds (Barry, 2002)
6.3	Emergency actions lasting a minute can be performed by personnel without shielding, but with appropriate clothing (API RP 521)
4.7	Emergency actions lasting several minutes can be performed by personnel without shielding, but with appropriate clothing (API RP 521)

5.11.1.2. Smoke and Gases

Smoke is composed of combustion gases, soot (solid carbon particles), and unburnt fuel. For outdoor fires, the impact of smoke is usually a secondary consideration after the heat transfer. In many circumstances, the immediate thermal threat from the fire plume (jet, pool, or flash fire) overwhelms the smoke threat, particularly for personnel in close proximity to the event. There may be circumstances where personnel are in a downwind smoke plume where there is no immediate thermal threat. As a rule-of-thumb, all people within a smoke plume may be immediately or nearly immediately affected and at risk from a life safety standpoint (be it from lack of visibility or by toxic products).

Estimates of visibility in smoke plumes have been made and are on the order of less than 1 meter near the source (i.e., high smoke concentration). Generic smoke dilution factors for large plumes have also been estimated and are presented in the CMPT Handbook (Spouge, 1999). Outdoor smoke plume models can be used to estimate the specific areas of smoke involvement.

Where personnel take refuge in a building from an outdoor fire, smoke infiltration into a building may be a concern. A methodology is available to estimate this impact based on the concentration of the material present outside of the building, the building ventilation rate, and the time of exposure (SINTEF, 1997; Lees, 1996).

The component of the smoke that has the quickest impact to people is carbon monoxide (CO). Table 5-6 illustrates the impact of carbon monoxide concentrations on personnel (Spouge, 1999).

Smoke infiltration may result from natural leakage openings (e.g., around ventilation ducting/grills), open doors, or breached fire barriers. The integrity of