## NIST Special Publication 1102

# FIRE FACTS

James Randall Lawson

National Institute of Standards and Technology • U.S. Department of Commerce

**NIST Special Publication 1102**

# FIRE FACTS

James Randall Lawson
Building and Fire Research Laboratory
*National Institute of Standards and Technology*

August 2009

U.S. Department of Commerce
*Gary Locke, Secretary*

National Institute of Standards and Technology
*Patrick D. Gallagher, Deputy Director*

**National Institute of Standards and Technology Special Publication 1102**
**Natl. Inst. Stand. Technol. Spec. Publ. 1102, 7 pages (August 2009)**
**CODEN: NSPUE2**

# FIRE FACTS
## Heat Flux, Temperature, & Thermal Response

***Abstract***

Fire Facts gives the reader an ordered series of heat flux values and temperatures that may be associated with fire growth conditions and relates specific human response to these thermal conditions. The thermal conditions are presented in ascending order relative to the potential for hazard. Use example: compare the time relationship between second degree burn response from heat flux and second degree burn response associated with temperature. Reference information is provided for all thermal conditions and response values.

Keywords: burn injury, fire, heat flux, humans, temperature, thermal response

### Discussion

Having an understanding of fire growth dynamics is essential to safety on the fireground. A discussion of some basic concepts related to fire growth and prevention of thermal injuries follows. A firefighter may arrive on the fire scene during any of the various stages of fire development, from initial burning to post flashover decay. The dynamic thermal environments associated with structure fires are primarily controlled by heat release rate (HRR).[1] What is heat release rate? The National Fire Protection Association standard, NFPA 921, defines heat release rate in the following way: - *The rate at which heat energy is generated by burning.*[2] Additionally, NFPA 921 defines temperature as: - *The degree of sensible heat of a body as measured by a thermometer or similar instrument.*[2] Essentially, the rate at which heat is release by a fire determines the size and intensity of the fire. Thermal energy measured as heat release rate has a direct impact on the temperatures associated with the fire environment.[1] Additionally, HRR, when combined with ventilation and compartment geometry, are major factors that influence the onset of flashover. Flashover is a transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature and fire spreads rapidly throughout the space, resulting in full compartment involvement.[2] Flashover of an average-sized family room will usually occur at a heat release rate of about 1000 kW, equivalent to the power used when energizing ten thousand 100 W light bulbs.[1]

Firefighters are exposed to varying thermal conditions that are generated by growing fires. There are two primary components to thermal exposures that impact the firefighter: 1) heat flux – *the rate of heat energy transfer to a surface*,[2] - and 2) temperature. These two types of thermal insult are physically coupled and work together as a dynamic condition that threatens the well-being of the firefighter. Often when humans think of dangers from fire, they think in terms of temperature and how temperature creates a burn injury. However, temperature related to fire environments is only a part of the threat; temperature is a measurable quantity that can be physically related to heat flux and is determined by the fire's HRR and other heating and cooling process that may be present. Fire gas temperatures and temperatures of firefighters' protective clothing, human skin, furnishings, etc., are the direct result of heat energy generated by the fire and transferred as heat flux to the surrounding environment. Therefore, heat flux is a driving force that causes temperatures to change in a fire environment. Simply, heat is transferred by three processes: 1) convection, the movement of hot gases or fluids; 2) thermal radiation, movement of heat by electromagnetic waves; and 3) conduction, transfer of heat by atoms through and between solids.[1] Each of these forms of heat flux has a direct impact on threats of burn injury, and they cause the changes in temperature felt by the firefighter. Therefore, when using FIRE FACTS one must always keep in mind this important relationship. ***It is a combination of heat flux and resulting changes in temperature that causes burn injuries.***

References:
[1] Lawson, J. Randall, NISTIR 5804, "Fire Fighter's Protective Clothing and Thermal Environments of Structural Fire Fighting," NIST, Gaithersburg, MD 1996.
[2] NFPA 921, Guide for Fire and Explosion Investigations, 2008 Edition, National Fire Protection Association, Quincy, MA 2009.

# FIRE FACTS
## Heat Flux & Response

This fact sheet provides information for a set of heat flux levels commonly experienced during firefighting operations and information on the human response to these heat flux levels. The unit $kW/m^2$ defines an amount of heat energy or flux that strikes a known surface area of an object. The unit (kW) represents 1000 watts of energy and the unit ($m^2$) represents a surface measuring one meter long and one meter wide. Example: 1.4 $kW/m^2$ represents 1.4 multiplied by 1000 and equals 1400 watts of energy on a surface area equal to one meter square.

| Heat Flux Level $kW/m^2$ | Response |
|---|---|
| ≈1 | A typical clear day solar flux on the earth's surface with direct solar radiation; a sun burn may occur in approximately 20 min to 30 min. [1] |
| 2.5 | Typical firefighter exposure and working environment [2] (About 2.5 times the solar flux). |
| 4.5 | Unprotected human skin will receive a second degree burn injury in about 30 s. [3] (About 4.5 times the solar flux) |
| 6.4 | Unprotected human skin has pain with 8 s exposure and blisters in 18 s with a second degree burn injury.[3] (About 6.4 times the solar flux) |
| 10 | Unprotected human skin will receive a second degree burn injury in about 10 s [3] (About 10 times the solar flux.) |
| 13 | Wood volatiles ignite with flame exposure.[4] (About 13 times the solar flux) |
| 16 | Unprotected human skin experiences sudden pain and blistering after 5 s exposure with second degree burn injury.[3] (About 16 times the solar flux) |
| 20 | Unprotected human skin will receive a second degree burn injury in less than 4 s [3]. This heat flux level represents the heat flux in a room at floor level at the beginning of flashover.[4] (About 20 times the solar flux) |
| 80 | Unprotected human skin will receive an instant second degree burn injury.[3] Flashover is established in a room.[4] (About 80 times the solar flux) |
| 84 | Heat flux level specified in the NFPA 1971 test for Thermal Protective Performance (TPP) to evaluate firefighters' thermal protective clothing.[3] |
| 170 | Maximum heat flux level measured by NIST with a post-flashover fire inside a burning room.[5] (About 170 times the solar flux) |

References:

1 Stickler, Greg; "Education Brief, Solar Radiation and the Earth System, Relating Solar Radiation Physics to Earth & Space Science Concept," NASA, http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/science-briefs/ed-stickler/ed-irradiance.html, 2009.
2 Donnelly, M.K., Davis, W.D, Lawson, J.R., Selepak, M.J., "Thermal Environment for Electronic Equipment Used by First Responders, NIST Technical Note 1474, 2006.
3 NFPA 1971, Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting 2007 Edition, National Fire Protection Association, Quincy, MA 2007
4 Lawson, D.I. and Simms, D.L., "The Ignition of Wood by Radiation, " British Journal of Applied Physics, 3, pp. 288-292. 1952.
5 4 Fang, J.B., and Breese, J.N., "Fire Development in Residential Basement Rooms," National Bureau of Standards (currently NIST), NBSIR 80-2120, Gaithersburg, MD, 1980

Second Edition prepared by J. Randall Lawson, NIST/BFRL Fire Research Division, August 2009

NIST
National Institute of Standards & Technology

BFRL
Building & Fire Research Laboratory

# FIRE FACTS

## Temperature & Response

This fact sheet provides information on temperatures commonly experienced during firefighting operations and information on the associated human response to these temperatures.

| Temperature °C (°F) | Response |
|---|---|
| 37.0 °C (98.6 °F) | Average normal human oral/body temperature [1] |
| 38 °C (101 °F) | Typical body core temperature for a working fire fighter[2] |
| 43 °C (109 °F) | Human body core temperature that may cause death [3] |
| 44 °C (111 °F) | Human skin temperature when pain is felt [4] |
| 48 °C (118 °F) | Human skin temperature causing a first degree burn injury [4] |
| 54 °C (130 °F) | Hot water causes a scald burn injury with 30 s exposure [5] |
| 55 °C (131 °F) | Human skin temperature with blistering and second degree burn injury [4] |
| 62 °C (140 °F) | Temperature when burned human tissue becomes numb [4] |
| 72 °C (162 °F) | Human skin temperature at which tissue is instantly destroyed [4] |
| 100 °C (212 °F) | Temperature when water boils and produces steam [6] |
| 250 °C (482 °F) | Temperature when charring of natural cotton begins [7] |
| >300 °C (>572 °F) | Modern synthetic protective clothing fabrics begin to char [7] |
| ≥400 °C (≥752 °F) | Temperature of gases at the beginning of room flashover [8] |
| ≈1000 °C (≈1832 °F) | Temperature inside a room undergoing flashover [8] |

References:
1 Klinghoffer, Max, M.D., “Triage Emergency Care Handbook,” Technomic Publishing Company, Inc., Lancaster, PA, 1985.
2 Veghte, James H., Ph.D., “Physiologic Response of Fire Fighters Wearing Structural and Hazmat Protective Clothing,” Second Annual Conference on Protective Clothing, Clemson University, May 1988.
3 Huck, Janice, “Evaluation of Heat Stress Imposed by Protective Clothing,” First Annual Conference on Protective Clothing, Clemson University, May 1987.
4 American Society for Testing and Materials, ASTM C1055, Standard Guide for Heated Systems Surface Conditions That Produce Contact Burn Injuries, 4:6, ASTM West Conshohocken, PA, 1997.
5 Bynum Jr., D. Dr., Petri, V. J., et. Al.; Domestic Hot water Scald Burn Lawsuits – The Who, What, When, Why, Where How; Annual ASPE Meeting; Indianapolis, Indiana, October 25-28, 1998.
6 Shugar, G.J., Shugar, R.A., Lawrence, B., “Chemical Technicians’ Ready Reference Handbook,” McGraw-Hill Book Company, New York, 1973.
7 Krasny, John F., Sello, Stephen B., “Fibers and Textiles, Fire Protection Handbook,” 16th Edition, 1986. NFPA, pp.5-27.
8 Fang, J.B., and Breese, J.N., “Fire Development in Residential Basement Rooms,” National Bureau of Standards (currently NIST), NBSIR 80-2120, Gaithersburg, MD, 1980.

Second Edition prepared by J. Randall Lawson, NIST/BFRL Fire Research Division, August 2009