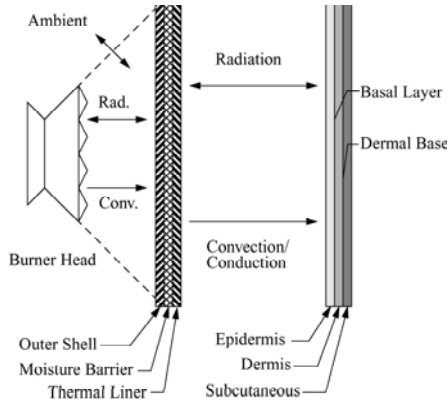


## Modeling Heat and Moisture Transport in Firefighter Protective Clothing during Flash Fire Exposure

Roger L. Barker, leader; Hechmi Hamouda, Andrey Kuznetsov, Donald B. Thompson (NC State)

We are developing a model of heat and moisture transport in firefighter protective clothing during a flash fire exposure. A traditional firefighter garment consists of three fabric layers (outer shell, moisture barrier, thermal liner) which transport heat and moisture to human skin and tissue (See Schematic). Human skin is also divided into three layers (epidermis, dermis, subcutaneous). Researchers have traditionally focused on heat transfer in fabrics during flash fire exposures, but moisture transport and its impact on protective performance of the garment has not been studied in sufficient detail.



### Model for Heat and Moisture Transfer in Fabric

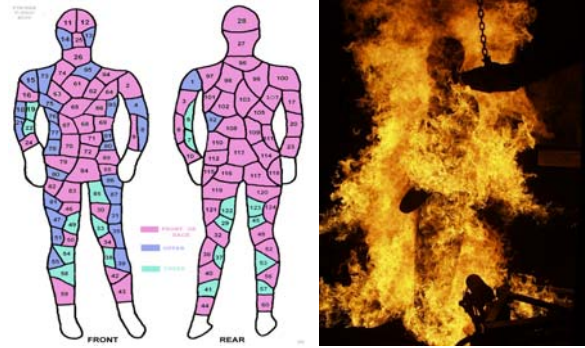
There are many existing models for the analysis of multiphase transport in porous media, such as protective fabric.

### We are developing a model to predict heat and moisture transport in firefighter protective clothing during flash fire exposures.

Gibson assumed that fabric can be modeled as a hygroscopic porous media and modeled the material as a mixture of a solid phase consisting of solid polymer fibers plus bound water absorbed by the polymer matrix, a liquid phase consisting of free liquid water, and a gaseous phase consisting of water vapor plus inert air. This model accounts for heat transfer by conduction in all phases, convection in the gas and liquid phases, and latent heat release due to phase change from liquid to vapor phase. Gibson's model is suitable for fabrics subjected to intensive heat, but it does not account for radiation heat transfer within the fabric layer. Torvi assumed that convective heat flux only applies to the surface of the fabric but radiative heat flux can penetrate through the fabric up to a certain depth. Thus, by modifying Gibson's model with Torvi's treatment for radiative heat, we have developed a model for thermal response in a composite fabric layer.

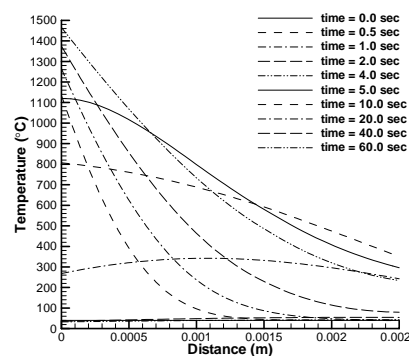
### Experimental Results

Pyroman<sup>®</sup> is an instrumented manikin housed in a chamber and equipped with heat sensors that measure exposure of a clothed body to a simulated fuel flash fire (See Figures at top right). The flash fire is dynamic and normally distributed over the manikin with average intensity of 2cal/cm<sup>2</sup>/sec. During 4 seconds of burning, sensors meas-



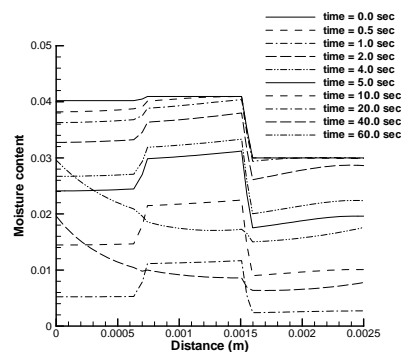
ure flame temperatures and their average flux at many locations on the manikin. After the fire is off, computations continue until the time reaches 60 seconds. Hot gas and ambient temperatures gradually decrease after 4 seconds.

### Temperature Distributions in Fabric vs. Time

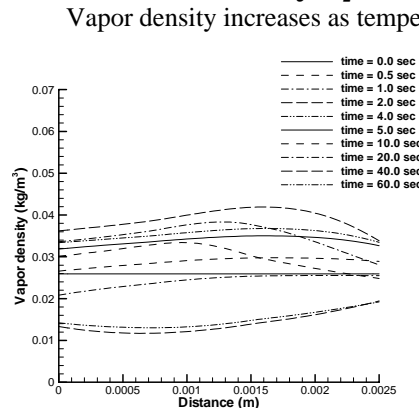


compared to those at the inner surface during cool-down.

### Distributions of Fabric Moisture Content vs. Time



### Distribution of Vapor Density vs. Time



The thickness of the air gap between the garment and the body depends on a particular location on the human body. By superimposing

When a garment is exposed to an intensive flash fire, the temperatures at the outer surface of the fabric increase much more rapidly than those at the inner surface (See Graph). Conversely, temperatures at the outer surface decline quickly compared to those at the inner surface during cool-down.

During flash fire exposure, fabric moisture content decreases and keeps decreasing until it reaches its minimum, but the difference in properties of each fabric layer causes moisture content to jump at the interfaces (See Graph).

causes the phase transition from bound water to water vapor (See Graph). Moreover, moisture moves from the outer shell to the moisture barrier and then to the thermal liner because of the temperature gradient.

nude and dressed 3-D body scanning data of Pyroman<sup>®</sup> we can plot a garment air gap distribution chart (see 6/2002 *Research Briefs*). The maximum air gap occurs for the leg but the minimum air gap occurs for the shoulder where human skin would first receive second and third degree burns from a given flash fire exposure (See Table). Shrinkage reduces the air space and increases layer-to-layer contact, thereby producing changes in heat transfer efficiency. We can now measure the air gap distribution before and after the fabric shrinkage that occurs during burning.

Location	Air gap thickness (mm)	Maximum duration of flash fire exposure for 2nd degree burn (sec)	Maximum duration of flash fire exposure for 3rd degree burn (sec)
TPP test	6.35 (or ¼")	13.81	31.25
Arm	6.58	13.85	31.33
Front	10.21	14.06	31.69
Back	5.93	13.73	31.15
Leg	18.50	14.12	31.76
Shoulder	1.60	11.48	27.58

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**Industry Interactions:** 2 [Beck Engineering Consultants, Southern Mills, [TC]<sup>2</sup>]; Non-NTC Academic Interactions: 2 [Michigan St. Univ.]; Others: Noish.

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