# THE PLOT THICKENS

## Turnout liner technology takes a turn with DuPont's Nomex on Demand

By Henry Costo

Despite considerable and continuous efforts during the last 15 years or so, not much has changed with regard to turnout gear composition and related thermal protective performance. Throughout this period, two fundamental concepts of NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, have shaped and guided the collective efforts of the personal protective equipment (PPE) industry to improve thermal insulation levels while ensuring wearer comfort. These basic—and inherently irreconcilable requirements—are thermal protective performance (TPP) and total heat loss (THL).

### THE TPP/THL CONUNDRUM

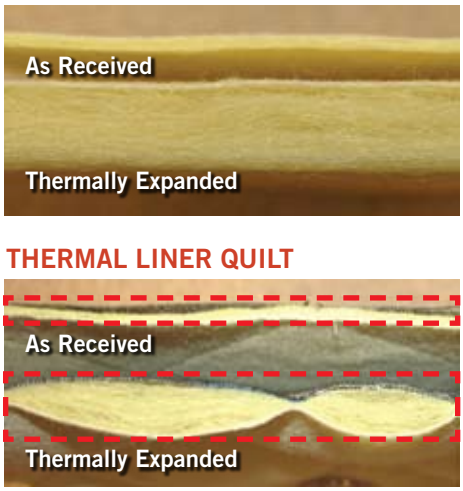
TPP is a relative measure of a composite garment's thermal insulation capability. A composite PPE garment is composed of an outer shell, moisture barrier and thermal liner. The TPP test was designed to measure the effects of a simulated flash fire impingement on a composite garment and then to calculate its relative thermal protective value.

Ostensibly, when halved, a TPP value will indicate the number of seconds it takes for the wearer to sustain a second-degree burn when exposed to an impingement of 2 calories/cm$^2$. *Example:* NFPA 1971 requires a composite protective garment to provide an average TPP of at least 35. Theoretically, a garment possessing this minimum TPP value would protect the wearer from sustaining a second-degree burn for 17.5 seconds (35/2 = 17.5) when exposed to a direct flame impingement of 2 cal/cm$^2$.

THL testing, on the other hand, is designed to measure the ability of a composite swatch to transfer dry and wet heat and then to use these measurements to quantify the relative capability of the garment to release/dissipate metabolic heat from its inside. NFPA 1971 requires that a garment composite be tested for such evaporative heat transfer and that it shall have a THL of at least 205 W/m$^2$.

It's worth noting that the testing method (ASTM F 1868, Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate) measures the heat transfer from the heated "inside" (simulating the wearer's body) to an ordinary, room-temperature "outside" of the garment. The calculated THL, therefore, should not be misconstrued as an indication of the composite's ability to release metabolic heat when operating in areas of elevated temperatures, such as those associated with an interior fire attack. *Simply put:* Heat will move from the hottest point to the coolest. Under testing conditions, this will be from inside the simulated garment to the outside. During interior fire attack, however, heat will travel from the garment's exterior to its interior.

# Nomex On Demand




Nomex on Demand is comparable to two or three layers of Nomex E89, but reacts with heat to form a thicker, more insulative structure. Shown is the raw material (top) and the material as incorporated into a liner (bottom).

The dilemma for firefighters, PPE researchers, PPE manufacturers and others desiring to improve the protective capabilities of turnout gear resides in the practical reality that TPP and THL are inversely related. Efforts to increase thermal protection (TPP), generally by making the composite "thicker" in some way, inevitably result in a commensurate reduction in the ability of the garment to release metabolic heat (THL). In short, when you increase TPP, you decrease THL.

Much to the consternation of PPE manufacturers and end-users alike, the "irreconcilable differences" between TPP and THL have meant that there must always be a trade-off between thermal protection and wearer comfort/mobility. Because of this reality, all PPE decision-makers have been compelled to strike an elusive balance between TPP and THL during the PPE specification and selection process. This decision is fundamental and crucial to firefighter safety. Sophisticated PPE decision-makers, therefore, will only make this vital decision after conducting a thorough and deliberate risk assessment specific to their respective jurisdictions.

## PPE THAT CHANGES?

Obviously, once the appropriate TPP-THL balance has been determined and specified, it remains more or less static for the duration of the contract and/or for the life of the garments purchased. After all, historically in the fire service the measure of PPE quality and performance has been thermal *stability* (i.e., the ability of a garment to remain unchanged during and after an attack by fire). Nomex, PBI, Kevlar, PBO, etc., were all developed to withstand changes during exposure to heat and flame. Indeed, most of the standards-related testing has been designed to ascertain whether or not a fiber, fabric, composite, etc., possesses the requisite thermal stability.

Recently, however, in an effort to surmount this frustrating TPP-THL dilemma, scientists at DuPont have taken a completely divergent approach to the issue of the thermal stability of turnout liner materials. In the process, those researchers have essentially shifted the long-standing paradigm that has been almost exclusively focused on the preservation and extension of thermal stability. They did so by inventing a liner material possessing engineered and controlled thermal *instability*. This less-thermally-stable, intumescent material can now be integrated into a composite turnout system, allowing for selective, and situationally appropriate, performance benefits.

The new "active" thermal liner, which DuPont calls Nomex on Demand, is designed to respond—expand or thicken—when the temperature of the material reaches 250 degrees F. Theoretically, the activated/expanded thermal liner should provide enhanced thermal protection during situations when firefighters face the greatest potential for sustaining burn injuries.

Testing of composites incorporating Nomex on Demand has indicated TPP improvements (following "activation" of the material) of 10–20 percent or more, depending upon the base composite tested and the testing methodology employed. A system with a TPP value of 39–40 can show improvement to 44–46. Again, this increase in TPP will occur only when needed (on demand).

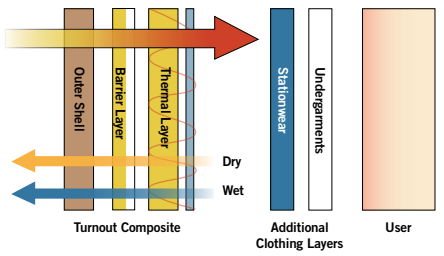
As it relates to the long-standing TPP-THL tradeoff necessity, the advertised benefit of this new product is that it eliminates the need to make such a difficult decision. DuPont believes it has created a thermal liner material that's thin, breathable and flexible under ordinary operating conditions (providing routinely high THL), but is capable of providing enhanced thermal protection (increased TPP) during emergent circumstances. Lab testing indicates that this new liner material will allow for the design of composite "lay-ups" possessing excellent THL numbers under routine conditions and outstanding TPP levels when needed most.

## CAVEATS & QUESTIONS

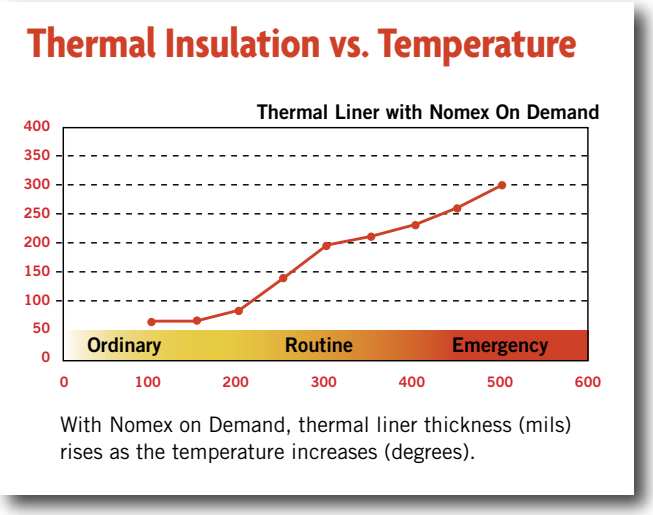
Keep in mind that not even its developers believe this new material to be a PPE panacea. It's simply intended to be another tool in the PPE design toolbox, and that's how end-users should perceive it. In addition, the material is so new that it has yet to be truly tested under field conditions. Thus its limitations have yet to be determined and questions remain to be answered.

For example, common sense suggests that the material needs to expand/thicken in order to have the designed effect. As the intumescent layer thickens, it will push heated outer layers of the PPE garment away from the wearer and, by doing so, reduce the likelihood and/or the severity of burns. When the liner is compressed (e.g., under SCBA straps), however, its ability

## Thermal Protection vs Heat Stress




Thermal insulation is a function of the thickness, weight and number of layers in the garment system. TPP (red arrow) is a relative measure of insulation against external heat penetration at emergency conditions. THL (blue and yellow arrows) is a relative measure of metabolic heat transfer at routine conditions.




With Nomex on Demand, thermal liner thickness (mils) rises as the temperature increases (degrees).

to expand will be restricted and its effectiveness reduced. So, although Nomex on Demand creators intend the new material to be employed throughout the entire thermal liner, it's possible that its true value may be realized through selective reinforcement applications. It could be employed, for example, in areas of garments that have traditionally been difficult to thermally reinforce without reducing mobility and/or comfort, such as the arms and the back of legs.

Other questions include:

- Once activated, what effect will an expanded liner have on overall THL and wearer comfort?
- What durability will the liner possess?
- How receptive will turnout manufacturers be to the new liner material?
- How will these manufacturers integrate the new material into their existing liner systems?
- What is the optimum orientation of the material within a composite system that will allow it to expand where and when it is needed?
- What will the inclusion of Nomex on Demand add to the price point of existing turnouts?

## MORE TO COME

Despite these and other yet-to-be determined limitations and lingering questions, there's no question that this novel product shows great potential to improve the protective performance of turnout gear. The concept of selectively increasing TPP only when needed (emergent circumstances) in order to maintain comfortable THL levels at all other times (routine operations) is exciting to say the least. The Philadelphia Fire Department will be among the first to field test garments incorporating this new technology. "Report to follow."

Battalion Chief Henry Costo is a 35-year veteran with the Philadelphia Fire Department. He has served as a safety officer for 6 years and serves as chairman of the safety committee for the International Association of Firefighters Local 22. He has a degree in fire science and graduated *suma cum laude* from University of Pennsylvania Wharton School of Business.