THE PLUG

BY JOHN TAYLOR & WARREN WHITLEY

Compartment fires create a dangerous "smoke plug" that must be controlled by air track management

During World War II, in the summer of 1944, Lloyd Layman, a visionary U.S. firefighter at the U.S. Coast Guard Fire Fighting School, first developed the concept behind the indirect firefighting technique. During a series of experimental fires involving 7,000 gallons of oil in an unseaworthy Liberty Ship's engine room, Layman applied this technique, inserting small water spray droplets into the fire compartment. But the technique was successful and extinguished the fire only when, in addition to applying the small water spray droplets, all the air vents apart from the exit port were closed off and the air intake was controlled. Only one exit port at the highest point remained open as an exhaust. Layman had, quite inadvertently, managed the *air track* of this fire.

Following Layman's amazing success, he coined the phrase "indirect firefighting." He'd proven that small water spray droplets can extinguish a fully-involved fuel fire because the water droplets are small enough to absorb energy (BTUs) and remove the heat from one side of the triangle of combustion.

Upon returning to terra firma, Layman adopted these very same techniques in his hometown fire department, the Parkersburg (W.Va.) Fire Department.

WHAT LAYMAN MISSED

When I (John Taylor) first read Layman's book, "Attacking and Extinguishing Interior Fires,"[1] I realized that he was describing about 90% of the theory that I'd been taught by Kristen Giselsson and Mats Rosander during a course in Sweden.[2] It was amazing to read the same tale, just with different terminology; it underscored that Layman, Giselsson and Rosander were simply explaining the *physics* of fire development—and physics, as we all know, conforms to certain "laws" that allow us to predict how things will act or react (e.g., Newton's Third Law of Motion).

However, the 10% Layman missed was a very important part of the fire development puzzle. Some 67 years ago, he demonstrated indirect techniques by inserting small water spray droplets into a wooden box (compartment) containing combustible materials that gave off combustible gases (smoke), which ignited (see diagram 1). The water spray droplets inserted into the compartment turned to steam, expanded and filled the compartment, displacing the flames and air through both openings (see diagram 2).

So what was the missing part of Layman's fire development puzzle?

DIAGRAM 1

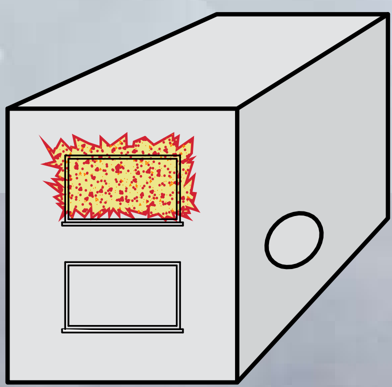

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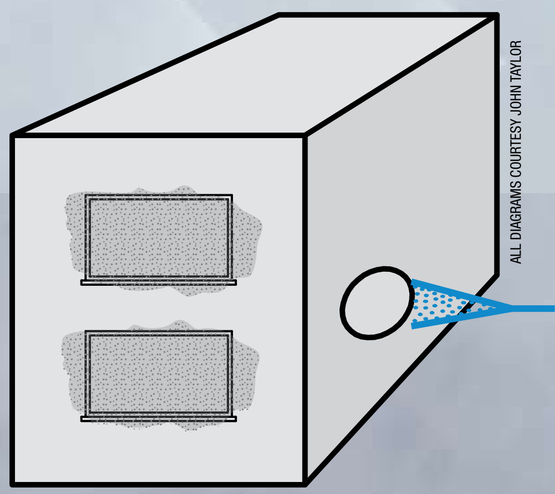
DIAGRAM 2



ALL DIAGRAMS COURTESY JOHN TAYLOR

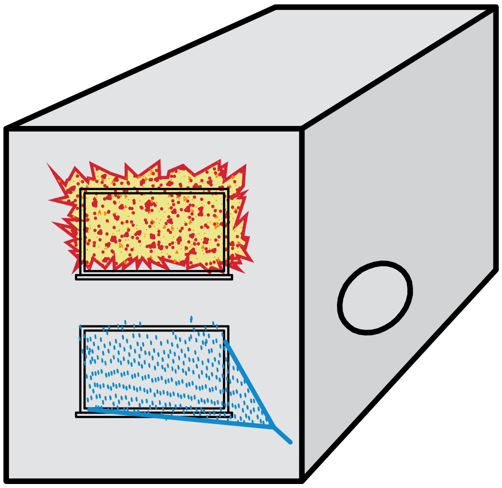


DIAGRAM 3: If the water spray droplets are fired into the "air track" on the under pressure, they flow through the bottom front opening into the base of the fire, then move up and outward, following the flames on the over pressure to fresh air. This extinguishes the fire without worsening the conditions at floor level inside the compartment.

The concept of "over pressure/under pressure." Or more simply, Layman's technique created conditions untenable for firefighters if applied internally.

Let's take another look at it to see why. Layman inserted small water spray droplets into the opening at the side of the box and observed the water spray droplets absorb the energy (BTUs) and turn it to steam/water vapor, which then expanded equidistantly through both front openings. He heated up the combustible materials in the rear of the box, which produced combustible gases (smoke) that subsequently ignited, producing flames, which exited the upper opening on "over pressure" (above atmospheric pressure). Once this positive pressure is created, physics must balance the equation by creating an "air track." Air is subsequently drawn into the box via the lower opening on "under pressure" (below atmospheric pressure). The technique works in extinguishing the fire, but in so doing, it makes the environment at floor level in the compartment intolerable for both firefighters and victims.

In the 1950s, another visionary U.S. firefighter, Bill Clark, wrote a brilliant book in which he described how he carried out some full-scale evaluations of Layman's techniques on acquired structure fires.[3] Clark concluded that because the steam/water vapor expanded equidistantly, it caused untenable conditions for firefighters to operate in without being scalded.

The result: Laymen's indirect extinguishing techniques were not embraced. The preference to use large, straight-stream water globules prevailed. If a long reach was required, firefighters were advised to bounce the straight stream off the ceiling to the rear of the compartment. It was thought that this turned the straight stream into water spray droplets that subsequently absorbed the energy (BTUs) of the hidden flames running the ceiling above a large black smoke layer far better than the conventional straight stream. Clark's work explains why Layman's theory wasn't embraced and actually exposes what was missing from Layman's theory. If Layman had been a bit more fortunate and misfired some water spray droplets into the "air track" on the under pressure, they would have flowed through the bottom front opening into the base of the fire, then moved up and outward, following the flames on the over pressure to fresh air. This would have extinguished the fire without making the conditions at floor level inside the compartment any worse (see diagram 3). Had Layman figured this out, he would have solved the whole fire development puzzle some 32 years before Swedish theories and techniques were unveiled to the fire service world.

THE SMOKE PLUG

Although the U.S. fire service didn't embrace Layman's techniques, the U.S. Navy did, and has been effectively using them since 1944. So what's the difference between a fire in a metal box compartment floating on water and a fire in a normal structure on terra firma?

If you accept that the combustible gases are on fire and that "smoke burns,"[4] and that Layman put out a heavily involved fuel fire

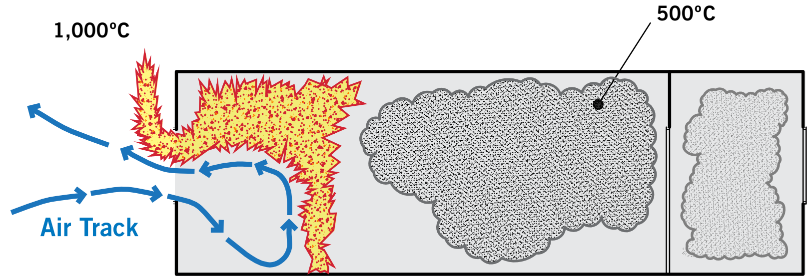


DIAGRAM 4: When the smoke can't escape the compartment, it creates a "plug" that absorbs the heat of the flames. If air is introduced into the compartment, the stored energy will be released with great force.

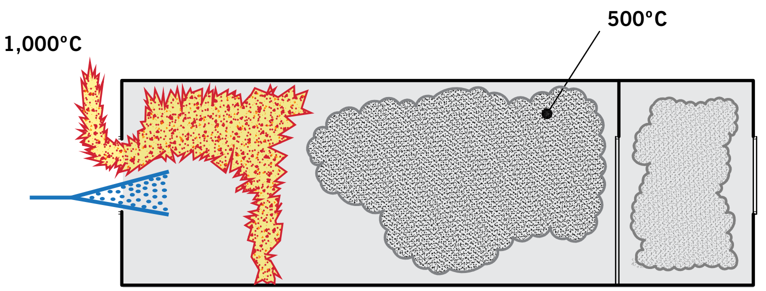


DIAGRAM 5: Using the "under pressure extinguishing technique" involves putting water spray droplets into the air track and extinguishing the fire without creating super-heated steam.

with small water spray droplets in conjunction with controlling the air, then consider this: If you factored in using "under pressure extinguishing techniques" instead of indirect techniques from the exterior on the burnt side of a structure fire and let physics do the work, then you would realize that these techniques are more effective than fighting a fire from the unburned side. That's because doing so releases something that we coined the "smoke plug."

The side view diagram of the plug (see diagram 4, p. 75) shows a fire developing in a single-story living room (compartment) with the seat of the fire near the closed single-pane window on the left-hand side. The smoke begins to collect in the ceiling and mushrooms toward the flames on the floor and becomes flammable, reaching the lower explosive limit (LEL). The fire flashes over the ceiling (lean flashover) both ways and quickly hits all four walls and then travels downward. The direct flame impingement on the glass breaks the single-pane window and allows air into the compartment through the bottom half of the window.

Flames exit through the top half of the window because the flames keep running the ceiling toward the closed entrance door, but can't escape out of this side of the compartment. Large amounts of black smoke collecting under the flame front generated by downward radiation of the flames can't escape. The black smoke begins to absorb the energy of the flames, exactly the same way small water spray droplets absorb heat. The major difference between water and smoke absorbing energy and extinguishing the flames is that the black smoke will store this absorbed energy. If air is then introduced to this rich mixture by opening the closed entrance door, and there's an ignition source already present, the energy stored in the black smoke will be unleashed with great force. However, if the entrance door remains closed and the integrity of the plug is maintained, then the flames can only go toward the window because of the back pressure of the plug.

Tip: With the flames showing halfway up the window and air entering into this compartment from the bottom half of the window on the air track, physics is telling you that the door to this compartment-

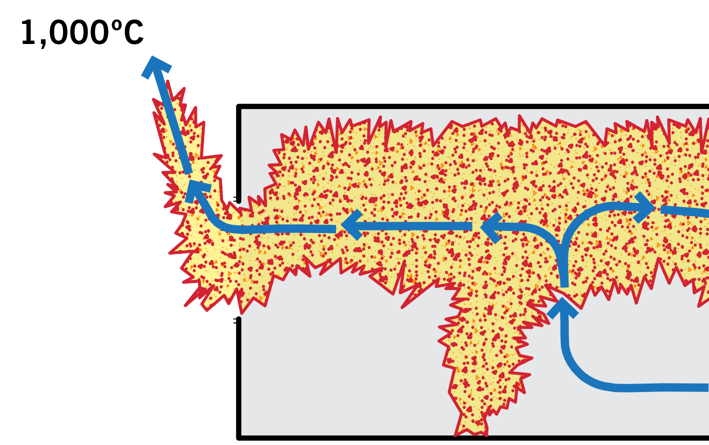


DIAGRAM 6: Opening the entrance door brings air into the room, causing flames to escape through the window and the door, forcing the black smoke (stored energy) out into a corridor already full of gray smoke and air. The addition of the gray smoke and air makes the rich smoke mixture leaner, enabling it to burn and move down the hallway.

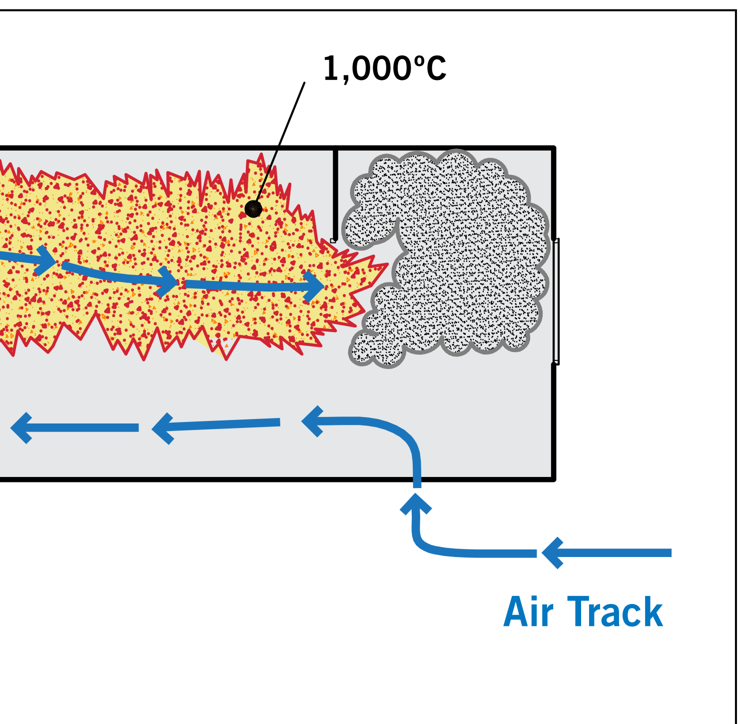
must be closed. If the flames were showing from the bottom of the windowsill upward, then the air supply for these flames must be from below the windowsill and the door to the compartment must be open.

The approximate temperatures shown in diagram 4 are 1,000 degrees C (1,832 degrees F) at the window, yet 500 degrees C (932 degrees F) adjacent to the closed entrance door, which proves that the black smoke isn't burning, because the plug is too rich to burn and there's a lack of air. The gray smoke shown in the corridor adjacent to the closed entrance door is seepage from the fire room compartment and will contain a substantial amount of carbon monoxide, which is flammable, explosive, invisible, odorless and capable of igniting if the entrance door is opened and a flame is introduced from the fire compartment into this mobile, combustible gas cloud.

MAKE THE PLUG WORK FOR YOU

If you acknowledge that these are indeed the circumstances upon arrival, why not make the smoke plug work for you and maintain this rich mixture that can't burn without air? Simply go to the window on the burnt side and use the "under pressure extinguishing technique," putting water spray droplets into the air track and extinguishing the fire without creating super-heated steam (see diagram 5, p. 75). More importantly, because you're not releasing the plug on the unburnt side of the building, you can fight the fire on one front only, instead of two fronts, which would be the case if you released the plug.

If you did decide to open the closed entrance door, air would enter the room and go to the seat of the fire on under pressure from the bottom half of the door, and flames would go up toward the ceiling and travel both ways toward the window and the now open entrance door. This time, the flames at the window would be from the windowsill upward, because the air supply from the bottom of the open door is below the windowsill. The flames would also be able to go toward the open entrance door, only this time they would be capable of exiting the room at the top half of the



door, which then forces all that black smoke (stored energy) out into a corridor full of gray smoke and air. The addition of the gray smoke and air makes the exiting rich smoke mixture leaner, enabling it to burn and move down the hallway (see diagram 6, p. 76–77).

If you stood underneath a bathtub full of water and decided to pull the plug out from below it, you would not be surprised if you got wet! So why release the lateral smoke plug and enable it to light off and travel freely through the internal side of the structure? Conversely, if you maintain control of the air flows (air track management) and keep the entrance door closed, you will only have to fight the fire on one front instead of two.

It's fairly easy to apply the "under pressure extinguishing technique" in a single-story room at the ground floor level. However, the diagram could well be a similar scenario you might face in a high-rise apartment fire. Many studies have documented the effect of wind in accelerating high-rise fires,[5] and these studies are instrumental in helping firefighters understand the conditions they may face in high-rises. However, there are two points we'd like to raise for discussion and further research related to wind-driven fires.

First, if there's a substantial wind blowing into the burning high-rise apartment and the entrance door remains closed, the smoke plug will be created adjacent to this door. If you maintain control of the air flows at the entrance door and you make the plug work for you and don't release it, wouldn't you prevent the wind-driven event from occurring? The methodology behind achieving this objective is another article's worth in its own right, but we believe that control of the air flows and subsequent search and rescue are doable from the entrance door of the apartment.

Second, if there was *no* wind on the day this high-rise apartment fire broke out and firefighters opened the apartment entrance door to gain access and left it open, do you really believe that the smoke plug would not be released just because there is no wind? On the contrary, it would burn both ways and spread into a hallway outside the apartment entrance door. Subsequently, if these burning gases then move from a hallway outside the apartment entrance door, to a narrower adjoining corridor, it's feasible that these burning gases would increase in velocity as the cubic space is decreased. This coincides with descriptions from firefighters at wind-driven high-rise fires—they describe flames coming down the corridor with the force of a "jet engine," even on a still, windless day.

MORE RESEARCH NEEDED

Despite advances in PPE, fewer fires and better educated firefighters, the number of line-of-duty deaths (LODDs) in the United States remains roughly the same as it has for many years. We believe that better understanding of fire behavior and air track management can make firefighters safer on the fireground. If we want to reduce LODDs, we owe it to ourselves and our families to evaluate air track management and under-pressure extinguishing techniques and either validate or refute these theories. What harm can it do to research them? If they're an improvement to firefighter safety, we all win.

John Taylor retired in 2004 after a 27-year career in the U.K. fire service. He has been involved in fire development research since an educational visit to Sweden in 1990 and was awarded a European Fire Engineering Diploma in 1991 by the Institution of Fire Engineers for his research paper on flashover training. Taylor has given fire development presentations in the U.K., Ireland, France, Germany and the United States. He has been collaborating with Prince William County Department of Fire and Rescue (PWCDFR) since 1994 and developed the Air Track Management Firefighters Course, which is currently being delivered to PWCDFR firefighters. Taylor is the author of "Smoke Burns," which explains why and how smoke burns, the importance of controlling air flows at fires and new search-and-rescue SOPs relating to these theories.

Warren Whitley is a 30-year veteran of the Prince William County (Va.) Department of Fire and Rescue and currently serves as an assistant chief. He is a member of the IAFC and the U.S. Branch of the IFE, and he holds an MPA from Virginia Tech and an MA from the Naval War College.

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