Carna Bunker Gear Literature Review

Carna Bunker Gear aims to shift the precarious, long-standing culture of outfitting firefighters in structural firefighting gear when training in atmospheres that are not immediately dangerous to life and health (IDLH). Structural firefighting gear (SFG) is composed of various poly hydrocarbon and synthetic materials that have been correlated to a variety of cancer diagnoses and life-threatening endocrine disruption among firefighters. Equally detrimental, SFG is routinely exposed to a wide range of carcinogenic chemicals at emergency operation scenes, which increases the firefighters' exposure exponentially to the aforementioned health risks. As a result of repetitive exposure to carcinogenic substances throughout their career, it is predicted that "70% of firefighters deaths will be from cancer."[1] The purpose of Carna Bunker Gear is to reduce the systemic carcinogenic load inflicted on firefighters and eliminate the unnecessary exposure to the endogenous and exogenous hazards associated with SFG. Carna Bunker Gear provides a carcinogenic free, sports-specific replica of SFG that can be utilized in non-IDLH training environments; thus, initiating a paradigm shift in firefighter health and rendering the longstanding culture of unnecessary SFG outfitting obsolete.

Firefighters train while wearing their structural bunker gear quite often, usually daily. There is little to no need to wear real structural firefighting bunker gear during training. Off the factory line many of the materials that protect firefighters and keep us safe from heat and hazardous fluids are inherently dangerous to the endocrine system. That means that carcinogenic chemicals are found in brand new gear without ever being exposed to smoke or fire. Add the exponentially high chemical exposure load on top of this initial danger and we have a recipe for disaster via high cancer rates and hormonal issues. So why are we still wearing our traditional thermal protective armor to train in when we don't need thermal protection?

How often do we need to wear real structural bunker gear during training? To gain a valuable perspective we will look at the state of Florida's Fire Academy requirements. In FL 492 hours of training are required in order to test for your state of FL fire certificate. Around ⅓ to ½ the time is spent in the classroom and ¾ to ½ the time is spent outside on the fire grounds. There they will wear partial or full bunker gear and personal protective equipment (PPE) during training; however, only two areas of training require protection according to NFPA 1971. These requirements are standard on thermal protection and "common liquids" protection. The first training requirement is live fire training. Around 40 minutes total is spent in IDLH live fire training environments. Each fire academy uses 4 live burn scenarios. Each burn is around 10 minutes of training in gear. The second form of potential training evolution that requires structural fire gear is vehicle extrication. This would consist of a 4–6-hour day in various scenarios that would require protection from common liquids i.e., battery fluid, gasoline, hydraulic fluid etc. In total a possibility of 7 out of 246 hours spent wearing bunker gear rated for NFPA 1971 is necessary. The same gear which contains various levels of chemicals associated with carcinogenic and hormonal disturbance effects. 239 hours could be spent in Carna Bunker Gear or 98% of the time. This trend continues into career firefighting were structural firefighter bunker gear doubles as daily PPE and training equipment. As we have discussed this extra time spent in structural fire gear is contributing simply unnecessary exposures to firefighters.

Structural Fire Gear (SFG)

SFG, also known as "bunker" or "turn out" gear is a "complex, multilayer garment designed for performance under extreme thermal conditions."[2] Bunker gear is composed of the outer layer which provides resistance to heat, water, and oil and provides shape for the layers beneath. Below that is the moisture barrier layer. This layer is usually manufactured with fluoropolymer polytetrafluoroethylene (PTFE) "Fluoropolymers are a group of polymers within the class of per- and polyfluoroalkyl substances (PFAS)."[3] PFAS are used in order to obtain water and oil repellent properties. PFAS are the only known chemical which can repel oil. The final layer closest to the skin is known as the "thermal layer," which wicks moisture. The combination of the three layers combine to provide protection from extreme heats and dangerous common fluids in the event they came into contact with the bunker gear.

A few of the important carcinogenic chemicals firefighters are exposed to at a higher rate than the public range from Polycyclic Aromatic Hydrocarbons (PAH) found in smoke and on fire scenes to flame retardants (PFAs) and even soft plastics in the form of phthalates (DEHP). The former two, PFAs and DHEP, are also found on fire scenes and are inherently in bunker gear itself. This is not an exclusive list of chemicals and their wide-ranging derivatives that firefighters are exposed to but simply an introduction to some of the heavy hitters. Structural bunker gear manufacturers have the duty to search for a better path forward for our PPE but firemen need to continue to improve decon and cleaning methods for their front line SFG. From this point forward we can limit our needless exposures from all of these carcinogenic chemicals during the vast majority of training by wearing Carna Bunker Gear. Below we will go more in depth on each of the toxins listed above that firefighters are exposed to at high levels.

The following definitions are taken directly from the Center for Disease Control and Prevention (CDC) and state government websites accompanied by citations from studies supporting their effect on humans and firemen.

Polycyclic Aromatic Hydrocarbons (PAH)

The CDC defines polycyclic aromatic hydrocarbons (PAHs) as "a class of chemicals that occur naturally in coal, crude oil, and gasoline."[4] PAHs result from burning coal, oil, gas, wood, garbage, and tobacco and have the ability to bind to or form small particles in the air.[4] Cooking meat and other foods with high heat will form, or yield PAHs.[4] Naphthalene is an example of a manmade PAH used in the United States (US) to make other chemicals and mothballs.[4] Cigarette smoke also contains many PAHs.[4]

In firefighting PAHs are found on all PPE including bunker gear zip flap, shoulders, hoods, helmets, gloves and SCBAs. A recent study identified that PAHS were found in all of the aforementioned components of bunker gear on each firefighter that was tested, even when the bunker gear was worn appropriately as it is intended for personal protective equipment (PPE).[5] The researchers concluded, "without robust protocols to mitigate such exposures, is likely to significantly increase exposure to carcinogenic PAHs."[5] Based on the results from the study, the researchers utilized a cancer risk scale to display their data numerically. According to the cancer risk scale, for every 1 in 100,000 firefighters, 350 firefighters can develop cancers from clothing contaminated with PAHs via dermal absorption.[5]

Per- and Polyfluoroalkyl Substances (PFAS/PFOS) or Oil & Fluid Repellents

According to the CDC, "per-and polyfluoroalkyl substances (PFAS) are a group of chemicals used to make fluoropolymer coatings and products that resist heat, oil, stains, grease, and water."[6] Fluoropolymer coatings can be in a variety of products including clothing, furniture, adhesives, food packaging, heat-resistant non-stick cooking surfaces, and the insulation of electrical wire.[6] Many PFAS, including perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), are a concern because they do not break down in the environment, can move through soils, contaminate drinking water sources, and build up, or bioaccumulate in fish and wildlife.[6]

The CDC articulates that PFAS are found in rivers and lakes and in many types of animals on land and in the water.[6] Human health effects from exposure to low environmental levels of PFAS are uncertain; however, studies of laboratory animals given large amounts of PFAS indicate that some PFAS may affect growth and development.[6] In addition, these animal studies indicate PFAS may affect reproduction, thyroid function, the immune system, and hepatotoxicity, as evidenced by epidemiologic studies that evaluated PFAS exposure on several health effects.[6]

PFAS have filled a role and have been useful in a variety of products primarily as oil repellents and secondarily in firefighting as flame resistant chemicals due to its ability to repel petroleum-based products and delay ignition. This directly affects firefighters and their bunker gear for both the good and bad. Firefighters' bunker gear also come in contact with environmental PFAS during structure fires. All of the household products that use PFAS like furniture, clothing, kitchenware Etc. are now being burned and released into the environment of firefighters in highly concentrated amounts. This study measured the levels of PFAs found in both the outer shell and the moisture barrier of 30 used and unused bunker gear samples and found that "very high" levels of fluorine (PFAS) were found in every single sample from these two layers of bunker gear.[1] They concluded that "Minimization of contact with PFAS-treated turnout gear could be done in much the same way firefighter safety has been improved by minimization of exposure to fire combustion products."[1] We would be providing one more tool to minimize exposure using Carna Bunker Gear.

The next study details the dangers of PFAS to humans in general and not accounting for the high rate of exposure firefighters experience with these chemical products.[3] "Given fluoropolymers' extreme persistence; emissions associated with their production, use, and disposal; and a high likelihood for human exposure to PFAS, their production and uses should be curtailed except in cases of essential uses."[3]

Polybrominated Diphenyl Ethers (PBDEs) & Polybominated Biphenyls (PBBs) or Flame Retardants

The CDC identifies that "polybrominated diphenyl ethers (PBDEs) and polybrominated biphenyls (PBBs) belong to a class of chemicals that are added to certain manufactured products in order to reduce the chances that the products will catch on fire."[7] Finished products that may contain PBDEs include furniture foam padding, wire insulation, rugs, draperies, and upholstery.[7]

Other PBDE-containing products include plastic cabinets for televisions, personal computers, and small appliances.[7] PBDEs replaced PBBs, which were used in the past; and one in particular, BB-153, has not been produced in the US since the 1970's.[7] PBDE and PBB chemicals can pollute the air, water, and soil during their manufacture; leak from the products that contain them; or escape when the products that contain them break down.[7] PBDEs and PBBs do not dissolve easily in water; in fact, these chemicals stick to particles and settle to the bottom of rivers or lakes.[7] The CDC reports that some PBDEs can build up in certain fish and mammals when they eat PBDE- or PBB-contaminated food or water."[7]

PBDEs are similar to PFAS and significantly impose health risks to firefighters, for they are found in unused bunker gear, as well as, used bunker gear that is contaminated from fire scenes. A current study evaluated firefighters' exposure to PBDEs from both fire-exposed and unexposed bunker gear, as well as, the respective implications to firefighter health.[8] The researchers revealed that "15 of the 17 PBDEs, for which analysis was performed were found on at least one clothing swatch" from each of the bunker gear samples.[8] Every single clothing sample, including ***unused*** gloves and hoods contained some level of PBDEs.[8] The researchers of the study concluded that "firefighters are exposed to PBDE flame retardants at levels much higher than the general public."[8]

Di(2-ethylhexyl)phthalate (DEHP) or Micro Plastics

The California government Proposition 65 (P65) lists di(2-ethylhexyl)phthalate (DEHP) to raise awareness to the public regarding the harmful effects of DEHP.[9] P65 reports that exposure to DEHP may increase the risk of cancer.[9] Additionally, DEHP can impose birth defects and harm to the reproductive system.[9] Exposure to DEHP can impair the reproductive system in males and impair child development in women exposed to DEHP during pregnancy.[9]

The P65 classifies DEHP as a phthalate, which is a chemical added to some plastics to make them flexible.[9] According to P65, DEHP was one of the most frequently used phthalates in plastic products, but its use has decreased in recent years for a variety of reasons.[9] Although production with DEHP has tapered, manufacturers continue to use DEHP as an ingredient in various types of plastic consumer products including shower curtains, furniture, automobile upholstery, garden hoses, floor tiles, and coverings on wires and cables.[9] DEHP is also found in day-to-day products, such as rainwear, shoes, lunchboxes, binders, backpacks, and plastic food packaging materials.[9] The P65 highlights that medical devices and equipment, including some types of blood and intravenous solution bags, tubing for dialysis, feeding tubes, oxygen masks, and surgical gloves also contain DEHP.[9]

Similar to PFAs, firefighters are overexposed to DEHP via both the wearing of their bunker gear and environmentally when working a fire, where DEHP chemicals from burning structures are ignited and released rapidly at high concentrations. A study evaluating the direct firefighter exposure to DEHP highlighted that "DEHP concentrations were the highest of any chemical measured, and were 52 to 875 times higher than any PAH concentration measured."[10] The DEHP measurement detected in this study is alarming, especially when considering the available data regarding the high rate of PAH exposures that firefighters already encounter. Equally concerning, the researchers of this study identified that DEHP was also found on most items of <u>unused</u> firefighter PPE, but at lower levels.[10] The researchers of this study warned that

"firefighters are exposed to high levels of DEHP Di(2-ethylhexyl) phthalate (DEHP), a probable human carcinogen, and at levels much higher than PAHs."[10]

Aqueous Wash Cycles Using Gear Extractors

As a safety protocol, firefighters clean, or "decontaminate," their bunker gear after every fire incident to remove exogenous carcinogenic chemicals exposed to the PPE during fires. It is also common practice for firefighters to clean their bunker gear after every training evolution to cleanse their gear of the large amount of sweat and associated unpleasant odor that saturates the material. This section discusses the results found in studies that evaluate the decontamination of SFG and the effectiveness of SFG decontamination in regard to the removal of carcinogenic chemicals.

Despite a thorough decontamination protocol of bunker gear, research demonstrates that the carcinogenic chemicals exposed to the bunker gear in various environments, such as a fire, remain in the PPE after cleaning, ultimately accumulating and wreaking havoc on firefighter health. Of all of the chemicals exposed to SFG, the laundering process is most effective in removing PAHs from the bunker gear. It is important to highlight; however, that the studies regarding the effectiveness of PAH removal with SFG laundering yield inconsistent results across the board. While some studies support that the SFG laundering process is effective in removing PAHs from the bunker gear, others report that the laundering process was ineffective and traces of PAHs remained after decontamination. For example, one study revealed that PAH and flame retardants (PBDE, OPFR) contaminated the bunker gear, even after returning from a professional cleaning.[11] The researchers of the referenced study, collected "surface wipes from uniforms across 12 fire stations, after they had returned from a laundering provider" and detected concentrations of 13 polycyclic aromatic hydrocarbons (PAHs), six organophosphate flame retardants (OPFRs) and seven polybrominated diphenyl ethers (PBDEs) in the collected samples."[11]

The researchers concluded that "the current laundering techniques do not appear to effectively remove PAHs, OPFRs and PBDEs at the measured concentrations from firefighters' uniforms."[11] The researchers also elaborate on the incomplete reduction in PHAs, as well as, the flame retardants' stubbornness to laundering. The researchers found a "statistically significant decrease in the concentration of PAHs after laundering; however, complete removal was not evident, and in only a few instances there was a reduction in individual OPFRs."[11] Overall the researchers concluded that laundering techniques appear to be inadequate for removing semi-volatile organic compounds (SVOCs)."[11]

Another smaller study did support that 'professional' laundering services were capable of reducing PAHs in two sets of bunker gear.[5] The researchers of this study stated that laundering has an "overall high decontamination efficiency," but is "dependent on the compounds present during decontamination" and the "process is not 100% efficient." While some studies reveal a degree of effectiveness that laundering has in regard to removing some PAHs, the conclusion that laundering SFG is not 'iron clad' and its ineffectiveness in removing PFAs, DHEPs, or PBDEs or other flame retardants and plastics chemicals found in bunker gear is unanimously consistent.[5,11]

Liquid CO2 Wash

Recently liquid CO2 has been studied as an alternate source to cleaning SFG. Liquid CO2 is better at removing PAHS and phthalate (DEHP) from SFG than traditional water-based gear extractor machines. We can see removal rates of PAHS from traditional gear extraction and liquid CO2 to be the most efficient for each wash. SVOCs and phthalate removal is where liquid CO2 shows increased efficiency in the decontamination process over traditional wash. Essentially traditional gear cleanings aqueous washing technique does not have the ability to effectively remove hydrophobic compounds. This is seen when comparing the two head-to-head in a study from 2022. Results indicate that the 6 samples of liquid chemicals assessed during this study had a removal rate anywhere from 90-98% yielding an average of 95%. Compared to traditional wash gear extraction of the same 6 chemicals yielding an efficiency of 68%.[12] The limitations of the study are that the chemicals applied were liquid chemicals not direct chemical contact via smoke and particulates that firefighters are exposed to on the fire ground, more studies must be conducted to replicate real life exposures. The authors also account for the limitations of liquid CO2 wash seen in the literature and in real life as having a reduced ability to remove large debris and dirt due to limited agitation during the washing cycle compared to traditional gear extraction. They have compared removal of large debris and contaminants in this manner to similar results seen during post decontamination protocols on scene after fires using a scrub brush. This study was conducted by NC State and liquid CO2 cleaning was performed by Tersus Solutions.

Companies selling Liquid CO2 wash machines and services have conducted in house studies by utilizing NFPA cleaning standards. We will report their findings due to the current lack of scientific evidence from academia.

EDT solutions has reported increased efficiency in removal of SVOCS compared to traditional wash. Using 11 chemicals they removed Phenol at 94%, 2-Nitrophenol at 83% 2,4,6-Trichlorophenol at 100% Acenaphthene at 89% Fluorene at 89% Diethyl phthalate at 94%, Phenanthrene at 89%, Anthracene at 89%, Pyrene at 89%, Di-n-octyl phthalate at 89%, for an Average SVOC removal of 91%. Compared to traditional gear extractor wash of 66%.[13]

Heavy metals found in lithium-ion battery fires were assessed and of the 8 chemicals studied yielded an average of 61% removal. Of these 8 chemicals cobalt scored the highest at 85% +- 8% removal rate.[14]

PFAS were studied using four different kinds of poly fluorinated chemicals. These tests were performed twice to achieve an average after 2 different washes. PFOA averaged 87%, PFTeDA averaged 97%, PFBS averaged 60%, PFOS averaged 91% making these four tests yield an average of 85%.[15]

Cost, access, and implementation of this technology is currently an issue but in the future SFG washing should move in this direction in capacity even if nothing more than being outsourced to clean once a year. The average price for liquid CO2 washing is about $100 per set of gear with the ability for a machine to wash 100 sets of gear in a week. Cost of a liquid CO2 machine is anywhere from $600,000 to $1,000,000.

The Cost of Laundering on Bunker Gear Structural Performance

What effect does laundering bunker gear have on its performance? While laundering in an effort to decontaminate SFG from carcinogenic chemicals is crucial, the impact that repetitive wear and tear that frequent laundering imposes on the overall integrity of the bunker gear is equally crucial to evaluate. The purpose of this section is to highlight the effects on the structural performance of SFG after repetitive washing cycles and its relevance to the benefits of reduced washing cycles that access to Carna Bunker Gear would provide.

The suspected impact that repetitive laundering has on the structural performance and integrity of SFG has been a longstanding concern among the fire community. Several studies have illuminated the points of a double-edged sword when it comes to the necessity of SFG decontamination. One study evaluated existing research regarding the effects of laundering on bunker gear structural performance and conducted their own study that consisted of 22 samples of SFG.[16] Each of the 22 bunker gear samples encountered up to 40 washing cycles, which followed the current edition of the NFPA 1851-2014 guidelines.[16] After each washing cycle, data was recorded regarding the integrity of the bunker gear.[16] The researchers identified that after only 10 wash cycles "negative impacts were seen in trap tear strength of the outer shell and thermal liner, moisture barrier liquid penetration for the Fuel H (hydrogen) challenge, and total heat loss of the composite."[16]

To thoroughly understand the results yielded in the study above, it is important to understand the composition of the SFG and the intended function. The thermal protective properties (TPP) of the bunker gear increased with laundering, but the total heat loss (THL) properties proportionally decreased; this is detrimental to the firefighter, for the firefighter will lose the ability to shed heat while wearing the bunker gear. The inability for the firefighter to regulate temperature can cause overheating or heat exhaustion in emergency situations, leading to decreased mental and physical performance. The study revealed a direct correlation between the age and number of washes of the bunker gear life cycle and the deterioration of the THL properties.[12] This is an important factor to consider by intentionally and drastically reducing the need to wash SFG when substituting Carna Bunker Gear for training. With access to Carna Bunker Gear, the need to wash SFG would be predominantly reduced to post- fire scene or training involving live fire or vehicle extrication. Echoing the results of studies evaluating the laundering efficiency in removing carcinogenic chemicals from the SFG, the researchers of this study reported "our result shows TPP increases with laundering, but not decontamination."[16]

The above referenced study, identified a dramatic reduction in the exterior shell and thermal liner tear strength of the bunker gear after 40 laundering washes.[16] Additionally, it was determined that several protective properties were altered.[16] Many of these reductions in performance dropped one standard deviation, while only two structural strength properties; the outer shell trap tear strength and outer shell seam strength, dropped below NFPA 1971 code.[16] Overall, the authors of the study found that "several important protective properties of turnout

gear are significantly changed after repeated (between 0 cycles and 40 cycles) simulated fireground exposures followed by cleaning (laundering, decon) or laundering alone."[16]

The information gathered in the study discussed above is not new knowledge. Repetitive laundering and the respective implications on SFG integrity was recognized as far back as 1992, when researchers of another study unveiled the "mechanical tear and seam strength values decreased between 10% and 30% with repeated laundering."[17] Despite existing knowledge on the detrimental effects of habitual, yet necessary, laundering of bunker gear, no advancement has been made in an effort to mitigate this issue, or reduce its occurrences. There is no reason to continue to decrease the performance of bunker gear in regard to thermal heat loss and seam strength properties via unnecessary wearing and laundering as a result of overuse in training situations that do not require the SFG-level protection in the issued front line PPE. Carna Bunker Gear provides fire firefighters in training, as well as, those on the frontlines with a solution to a longstanding problem.

Liquid CO2 reports to have less wear and tear on gear but more studies are needed.

Sport and Job Specific Training

In the world of sports training, we want to mimic the sports requisite demands while inflicting the least amount of damage to our bodily structure. This involves training the appropriate energy systems, the right muscle groups, the proper motor patterns, the mind, and utilizing proper training equipment. Utilizing safe and effective training equipment is vital in developing athletes and developing firefighters.

The NFL utilizes different training helmets and gear on game day versus in practice. Within the last few years, we see practice helmets being worn to try and reduce concussions. The military and police use dummy rounds when performing training evolutions to reduce the risk of being shot and killed while training. Fire fighters need to utilize that same mentality. Separating our training gear from our front-line gear is a new standard we must adopt.

Using training gear that mimics structural firefighter bunker gear in design, bulk, weight, and heat retention is essential for proper training. The user must have the same feeling of restricted mobility, due to extra bulkiness. Increased weight on their body frame and the same increase in core body temperature due to the reduced ability to cool the body off because of trapped heat within the gear. Wearing sweatpants or a trash bag simply won't provide the same sensory stimulus or appropriate training environment. As we have discussed, wearing front line bunker gear will obviously mimic the job requirements but adds unnecessary carcinogenic load and reduces PPE performance due to laundering requirements. Only Carna Bunker Gear provides all of the benefits of training in gear with NONE of the risks.

Ideal times to wear Carna Bunker Gear would include the following training evolutions. Donning and doffing, search and rescue, fire hose training, establishing a water supply, throwing ladders, forcible entry, RIT and survival training, aerial operations, operating the fire pump, any full gear physical fitness activities like team or individual circuit training. Even public education events such as school events or open houses. Use your imagination to come up with any

variation of the individual or combined activities and you have successfully implemented a harm reduction model to the vast majority of your training evolutions.

Limitations

Carna Bunker Gear is ***not*** to be used in IDLH training or training scenarios that impose a risk to exposures from NFPA 1971 common fluids such as, foam (AFFF), chlorine, battery acid, hydraulic fluid, gasoline, and antifreeze fluid. IDLH training or training scenarios that impose a risk to exposures from NFPA 1971 common fluids includes live fire training scenarios, Hazmat, and vehicle extrication training involving any potentially harmful liquid or vapor chemical.

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