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THESIS

THE IMPLICATIONS OF NANOTECHNOLOGY FOR THE FIRE SERVICE: AVOIDING THE MISTAKES OF THE PAST

by

Daniel John O'Sullivan

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Thesis Co-Advisors: Lauren Wollman
Glen Woodbury

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13. ABSTRACT (maximum 200 words)

Firefighters are exposed to numerous hazardous materials throughout their careers. Managing that exposure is essential for the health and safety of the fire service. This thesis examines how exposure to nanotechnology will impact the fire service in the future. This cutting-edge technology has the potential to revolutionize numerous industries by improving a wide variety of products including fabrics, electronics, furniture, and building materials that can break down in the uncontrolled environment of a structural fire. As industries race to incorporate nanotechnology into everyday products, those exposed to the material as it degrades may face dangerous health complications.

Given the newness of this technology, and the evolving scientific data, this thesis examines known hazards that have plagued the fire service to provide guidance on how to manage exposure to nanomaterials. Carbon nanotubes have been found to interact with lung tissue in ways similar to asbestos fibers. They have also been found to be a part of the particulate matter in diesel exhaust. Both hazards are examined to show how they have progressed and what measures have been taken to minimize exposure to them. The connection to these hazards demonstrates why it is so critical for the fire service to be aware of this new technology. It also offers guidance on the most effective methods to use to mitigate exposure.

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THE IMPLICATIONS OF NANOTECHNOLOGY FOR THE FIRE SERVICE: AVOIDING THE MISTAKES OF THE PAST

Daniel John O'Sullivan
Captain, Fire Department, City of New York
B.S., Manhattan College, 1996

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Approved by: Lauren Wollman
Thesis Co-Advisor

Glen Woodbury
Thesis Co-Advisor

Erik Dahl
Associate Chair for Instruction
Department of National Security Affairs

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ABSTRACT

Firefighters are exposed to numerous hazardous materials throughout their career. Managing that exposure is essential for the health and safety of the fire service. This thesis examines how exposure to nanotechnology will impact the fire service in the future. This cutting-edge technology has the potential to revolutionize numerous industries by improving a wide variety of products including fabrics, electronics, furniture, and building materials that can break down in the uncontrolled environment of a structural fire. As industries race to incorporate nanotechnology into everyday products, those exposed to the material as it degrades may face dangerous health complications.

Given the newness of this technology, and the evolving scientific data, this thesis examines known hazards that have plagued the fire service to provide guidance on how to manage exposure to nanomaterials. Carbon nanotubes have been found to interact with lung tissue in ways similar to asbestos fibers. They have also been found to be a part of the particulate matter in diesel exhaust. Both hazards are examined to show how they have progressed and what measures have been taken to minimize exposure to them. The connection to these hazards demonstrates why it is so critical for the fire service to be aware of this new technology. It also offers guidance on the most effective methods to use to mitigate exposure.

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LIST OF ACRONYMS AND ABBREVIATIONS

CNT	carbon nanotubes
CT	computed tomography
EPA	Environmental Protection Agency
ETIPC	Emerging Technologies Interagency Policy Coordination Committee
EU	European Union
FDA	Food and Drug Administration
IARC	International Agency for Research on Cancer
MARG	Methane Awareness Resource Group
MSDS	material safety data sheet
NCI	National Cancer Institute
NIOSH	National Institute for Occupational Safety and Health
NMSP	Nanoscale Materials Stewardship Program
NNI	National Nanotechnology Initiative
OSHA	Occupational Health and Safety Administration
PEL	permissible exposure limit
PM	particulate matter
PPE	personal protective equipment
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
REL	recommended exposure limit
SDS	safety data sheet
TSCA	Toxic Substance Control Act
WHO	World Health Organization
WTC	World Trade Center

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EXECUTIVE SUMMARY

The fire service is faced with many health threats due to exposure to dangerous materials. Often, the extent of the threat is not fully realized until long after the material has become established. To avoid repeating this pattern, this thesis examines nanotechnology and what hazards are associated with exposure to nanomaterials for firefighters. In a study performed by Mercer et al., the results indicate that carbon nanotubes (CNT) can cause a reaction similar to that of asbestos fibers when inhaled.[1] These are alarming results for firefighters, as material containing CNT will deteriorate in a fire. It has also been discovered that CNT are produced during the combustion of diesel fuel.[2] The consequences of diesel exhaust exposure have been well documented. As a result, the International Agency for Research on Cancer (IARC) classified diesel exhaust as a carcinogen.[3] The connection that this new technology shares with those known hazards indicates the significance of the risk while at the same time providing guidance on how best to manage the threat.

Nanotechnology is the manipulation of matter on the atomic scale to create materials with greater strength and stability. One such application is the construction of CNT through the manipulation of carbon atoms into a honeycomb lattice sheet that is then rolled into cylinders.[4] These cylinders can have a wide range of lengths with a hexagonal structure that makes them stronger than steel while at the same time three to five times lighter.[5] Such properties ensure that they will be incorporated in as many

[1] Robert R. Mercer et al., “Pulmonary Fibrotic Response to Aspiration of Multi-Walled Carbon Nanotubes,” *Particle and Fibre Toxicology* 8 (2011): 5, https://doi.org/10.1186/1743-8977-8-21.

[2] Heejung S. Jung et al., “Carbon Nanotubes among Diesel Exhaust Particles: Real Samples or Contaminants?,” *Journal of the Air & Waste Management Association (1995)* 63, no. 10 (October 2013): 1199–1204.

[3] “Diesel Exhaust/Diesel Particulate Matter,” Occupational Safety and Health Administration, accessed August 19, 2017, https://www.osha.gov/dts/hazardalerts/diesel_exhaust_hazard_alert.html.

[4] “CNT Technology Overview,” nanoScience Instruments, accessed October 22, 2016, http://www.nanoscience.com/applications/education/overview/cnt-technology-overview/.

[5] Amal M. K. Esawi and Mahmoud M. Farag, “Carbon Nanotube Reinforced Composites: Potential and Current Challenges,” *Materials & Design* 28, no. 9 (2007): 2394, https://doi.org/10.1016/j.matdes.2006.09.022.

products as possible. The inhalation of those CNT during fire operations is the most critical exposure route for the fire service. Animal studies have demonstrated that when CNT are inhaled, there are a number of harmful effects including fibrosis and scarring of the lungs.[6] As with any new technology, however, the extent of the damage that CNT inflict on lung cells is being debated. A study performed by Thurnherr et al. indicated that lung cells remain viable after exposure to some CNT.[7] As scientists continue to investigate the consequence of exposure to CNT, the fire service needs to develop procedures to minimize that exposure. Given the similarities in exposure vectors and reaction to asbestos, the most logical place to start is with the current protocols for asbestos exposure.

This thesis also examines the case of diesel exhaust, which contains incidentally occurring CNT as part of the particulate matter created during the combustion of diesel fuel.[8] While it has long been known that diesel exhaust contained carbon-based particles, CNT have only recently been examined to determine what part they may play in diseases such as asthma. Diesel exhaust exposure has long been an issue that the fire service has struggled with and continues to struggle with to this day. Diesel engines were incorporated into the fire service due to their power and dependability without due regard for the effect of diesel exhaust on firefighters. As with asbestos exposure, the fire service needs to look at the precautions currently required with diesel exhaust to develop protocols for managing exposure to CNT.

This thesis also examines how nanotechnology is currently regulated on the federal level. Local jurisdictions look to federal regulation to determine the best approach to handling new materials. In this case, the United States relies on a largely de-centralized regulatory structure with regulatory oversight divided among several different federal

[6] Mercer et al., "Pulmonary Fibrotic Response to Aspiration of Multi-Walled Carbon Nanotubes."

[7] Tina Thurnherr et al., "A Comparison of Acute and Long-term Effects of Industrial Multiwalled Carbon Nanotubes on Human Lung and Immune Cells in Vitro," *Toxicology Letters* 200, no. 3 (February 2011): 176–86, https://doi.org/10.1016/j.toxlet.2010.11.012.

[8] "Diesel Exhaust/Diesel Particulate Matter."

agencies.[9] The problem is that nanomaterials are being managed largely within the framework of the current laws and regulations that each agency possesses. While economic and trade interests dominate the regulatory discussion, health and safety concerns continue to be debated. The fire service must consider the potential consequences of this new technology and develop precautions on its own to manage the handling of the material effectively.

As the fire service continues to struggle with the effects of asbestos and diesel exhaust exposure, safety protocols must be created to address this new technology. By prioritizing health and safety measures while this new technology is being developed, the fire service can avoid mistakes made in the past while at the same time establishing a template that can be used for potential hazards in the future.

[9] Robert Falkner and Nico Jaspers, "Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap," *Global Environmental Politics* 12, no. 1 (January 13, 2012): 42, https://doi.org/10.1162/GLEP_a_00096.

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I would like to dedicate this thesis to my father. He was the hardest-working man that I have ever met. An immigrant from Ireland, he was self-taught in a wide variety of skills and valued education and hard work throughout his entire life. Through his examples of love, strength, and perseverance, he taught me everything I know about what it means to be a man.

I love him and I will always carry him in my heart.

Patrick J. O’Sullivan
1933–2017

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I. INTRODUCTION

A. PROBLEM STATEMENT

Nanotechnology represents a revolutionary industry with a wide array of applications in chemistry, biology, industry, and electronics. Through the manipulation of atoms, materials are constructed with new and unique properties, such as increased surface area, greater electrical and thermal conductivity, and increased strength to weight ratio. To visualize the scale of the material, one nanometer is one-billionth of a meter, which is approximately 10,000 times smaller than a human hair.[1] Nanotechnology is a platform-based technology, which means that it can be used to improve a variety of products. Scientists have used it to create nanoparticles that can distribute medicine directly to diseased cells.[2] The nanoparticles absorb the drug onto the surface area and are tailored to impart the drug directly to a specific type of cell.[3] They have also developed nanomaterial that increases the capabilities of electronics while reducing the weight, as well as composite nano-fibers that improve the fabric without added thickness or stiffness.[4] Increasing strength and conductivity while reducing weight allows for greater electrical efficiency and less energy expenditure.

The increased strength and lighter weight is achieved through the construction of carbon nanotubes (CNT). The carbon atoms are manipulated into a honeycomb lattice sheet and then rolled into cylinders to form the nanotubes.[5] They can be manufactured or combustion generated and are detectable in exhaust from propane, natural gas, methane,

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[1] "CNT Technology Overview," nanoScience Instruments, accessed October 22, 2016, http://www.nanoscience.com/applications/education/overview/cnt-technology-overview/.

[2] "Nanotechnology Applications: A Variety of Uses," Understanding Nano, accessed November 2, 2017, http://www.understandingnano.com/nanotech-applications.html.

[3] Rajesh Singh and James W. Lillard, Jr., "Nanoparticle-Based Targeted Drug Delivery," *Experimental and Molecular Pathology* 86, no. 3 (June 2009): 215, https://doi.org/10.1016/j.yexmp.2008.12.004.

[4] "Nanotechnology Applications: A Variety of Uses."

[5] "CNT Technology Overview."

and diesel fuel.[6] The hexagonal structure of the material gives them strength and stability while allowing for less material. In fact, CNT possess an elasticity and tensile strength that makes them stiffer and stronger than steel, but are three to five times lighter than steel.[7] These properties have enabled CNT to improve products, such as ceramics, biosensors, solar cells, military technology, textiles, and surface finishes.[8] The potential to affect so many different industries is so pronounced that the global market for CNT is anticipated to reach $3,812 million by 2022.[9] The problem with such overwhelming demand is that while the technology is swiftly being adapted for use, the possible safety and health issues have yet to be fully understood.

Science is attempting to determine what effect nanotechnology has on those who are exposed to it before its use becomes too vast. CNT are being developed without a full understanding of the physiological consequences of exposure.[10] Some studies indicate that the inhalation of CNT can indeed have dire consequences. Researchers have demonstrated that CNT can cause inflammation to lung tissue, granulomas growths in the lungs, inflammation to other organs through dispersion, and fibrosis of the lungs.[11] Those effects have led to a comparison of CNT exposure to that of asbestos exposure in the past. The similarities have led much of the research to focus on how industrial workers

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[6] Barbara P. Barna, Marc A. Judson, and Mary Jane Thomassen, "Carbon Nanotubes and Chronic Granulomatous Disease," *Nanomaterials (Basel, Switzerland)* 4, no. 2 (2014): 508, https://doi.org/10.3390/nano4020508.

[7] Amal M. K. Esawi and Mahmoud M. Farag, "Carbon Nanotube Reinforced Composites: Potential and Current Challenges," *Materials & Design* 28, no. 9 (2007): 2394, https://doi.org/10.1016/j.matdes.2006.09.022.

[8] Scientific Committee on Emerging and Newly Identified Health Risks, *The Appropriateness of Existing Methodologies to Assess the Potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies*, SCENIHR/002/05 (Brussels, Belgium: Scientific Committee on Emerging and Newly Identified Health Risks, 2006), 5, http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_003b.pdf.

[9] "Carbon Nanotubes Market by Type, Application and End-User—Global Opportunity Analysis and Industry Forecast, 2014–2022," Allied Analytics LLP, accessed October 22, 2017, https://www.researchandmarkets.com/reports/3934620/carbon-nanotubes-market-by-type-application-and.

[10] Scientific Committee on Emerging and Newly Identified Health Risks, *The Appropriateness of Existing Methodologies to Assess the Potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies*, 4.

[11] Robert R. Mercer et al., "Pulmonary Fibrotic Response to Aspiration of Multi-Walled Carbon Nanotubes," *Particle and Fibre Toxicology* 8 (2011): 5, https://doi.org/10.1186/1743-8977-8-21.

would react to being exposed.[12] The objective is to give scientific-based guidance for the safe handling and manufacturing of CNT. In fact, that guidance has lead the National Institute for Occupational Safety and Health (NIOSH) to propose a recommended exposure limit (REL) for CNT not to exceed 1.0μg/m^3 as an 8-hour time-weighted average for a 40 hour work week.[13] This limit represents the maximum amount that workers should be exposed to over their lifetimes to maintain health and safety. As a point of reference, current REL for larger carbon-based particles, such as graphite or carbon black, are between 2.5 and 5 mg/m^3.[14] That exposure limit is 2–5 thousand times greater for the larger particles, which indicates that NIOSH recognizes the need to keep exposure to CNT in the workplace at exceedingly low levels.

While guidance has been issued on exposure levels for workers, no such guidance has been released for accidental exposure. Workers who handle the material are informed about the potential hazards and have been given the proper personal protective gear and training. Firefighters, however, unaware of the threat, have no measures in place for the proper handling of nanomaterial or decontamination after exposure. The proliferation of nanotechnology guarantees that the fire service will come in contact with CNT in the future as part of the toxic environment generated during a structural fire. The long-term consequence of such interactions has yet to be realized. The exposure level that firefighters will be subjected to has not even been considered. In fact, very few experiments have examined the consequences of CNT released due to fire.[15] One study did examine the results of burning material containing nanotechnology and found that CNT are released in the process. When the material was exposed to fire at a temperature of approximately 650ºC, the CNT were effectively consumed.[16] An analysis of the char

[12] Department of Health and Human Services, *Occupational Exposure to Carbon Nanotubes and Nanofibers: Current Intelligence Bulletin 65* (Washington, DC: Department of Health and Human Services, 2013), iv, https://www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf.

[13] Ibid., 43.

[14] Ibid., 44.

[15] Lukas Schlagenhauf, Frank Nüesch, and Jing Wang, “Release of Carbon Nanotubes from Polymer Nanocomposites,” *Fibers* 2, no. 2 (March 28, 2014): 117, https://doi.org/10.3390/fib2020108.

[16] Marc R. Nyden et al., “Characterizing Particle Emissions from Burning Polymer Nanocomposites,” *ResearchGate*, January 1, 2009, 718, https://www.researchgate.net/publication/268367350_Characterizing_particle_emissions_from_burning_polymer_nanocomposites.

and ash revealed a concentrated amount of CNT left over.[17] Following the burning of the material, the remaining char was agitated and samples of the atmosphere were studied. The samples revealed that significant amounts of CNT particles were discharged into the atmosphere due to the agitation.[18] In the confined environment of a structural fire, a very high concentration of free CNT will be in the air. It is at this stage of operations that firefighters will suffer the greatest amount of exposure. This thesis considers the issue of how that exposure can best be managed by looking at how materials with parallels have been managed in the past. Asbestos is examined due to the similarities in physiological response to CNT and diesel exhaust is examined due to the presence of naturally occurring CNT as a byproduct of combustion.

The first case study looks at asbestos due to the correlation between the effects of inhaling CNT and asbestos fibers. CNT can form rope like fibers similar in shape and durability as asbestos. They can possess structural similarities to that of asbestos fibers.[19] This similarity has raised the possibility that exposure to CNT can have similar consequences as asbestos exposure. Researchers have tested that hypothesis and found that some CNT can indeed cause inflammation and a fibrotic or scarring response analogous to that of asbestos.[20] Given the fact that the fire service has suffered extensively, and is continuing to suffer from the effects of asbestos exposure, it is important to examine asbestos in this context. Firefighters can face lethal consequences, such as cancer and mesothelioma, when exposed to CNT as particulate matter during a fire.[21] The similarities between the two materials indicate that a crucial lesson can be learned from the example of asbestos use and the detrimental effects caused by that use for the fire service. In the absence of definitive guidance for exposure to CNT, it is prudent to examine how asbestos was handled to draw conclusions about what challenges

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17 Nyden et al., "Characterizing Particle Emissions from Burning Polymer Nanocomposites," 718.

18 Ibid.

19 Department of Health and Human Services, *Occupational Exposure to Carbon Nanotubes and Nanofibers: Current Intelligence Bulletin 65*, 13.

20 Ibid.

21 Ken Donaldson et al., ed., *The Toxicology of Carbon Nanotubes*, 1st. ed. (New York: Cambridge University Press, 2012), 99.

will be faced. The fire service can then apply the lessons learned from asbestos to determine what practices would be most effective in mitigating the effects of exposure to CNT.

The second case study looks at the particulate matter in diesel exhaust fumes. As noted, CNT can be generated via combustion and have been identified as a byproduct of diesel exhaust. Researchers have examined the particulate matter produced during combustion of diesel fuel and observed the presence of CNT.[22] This observation is significant, as the International Agency for Research on Cancer (IARC) has classified diesel exhaust and diesel particulate matter as a known human carcinogen.[23] By classifying it that way, they acknowledge that sufficient evidence exists to show a connection between exposure to these products and cancer in humans. The increased surface area of the CNT allow for a greater amount of chemicals to adhere to the particles and therefore migrate deep into the lungs. The fire service relies heavily on diesel-powered trucks and has struggled for years to manage diesel exhaust byproducts effectively. By studying the case of diesel exhaust and diesel particulate matter exposure, the fire service will recognize how rapidly a hazard can develop. The connection with CNT suggests that the hazard of diesel exhaust and how it has been handled is a valuable example to examine. The numerous studies of cancer rates in firefighters due to diesel exhaust exposure demonstrate how difficult it is to manage a health threat once it has advanced. The current recommendation for controlling diesel exhaust exposure can then be applied to this newly emerging risk.

The crucial first step to securing the health and safety of firefighters is to become aware of the hazard that exists. Given the slow nature of gaining institutional awareness, changing firefighting procedures, and getting regulation passed, the threat that CNT pose must not be discounted. Since the fire service has not yet considered this threat, the consequences and costs associated with managing it have not been anticipated. To

[22] Heejung S. Jung et al., "Carbon Nanotubes among Diesel Exhaust Particles: Real Samples or Contaminants?," *Journal of the Air & Waste Management Association (1995)* 63, no. 10 (October 2013): 1199–1204.

[23] "Diesel Exhaust/Diesel Particulate Matter," Occupational Safety and Health Administration, accessed August 19, 2017, https://www.osha.gov/dts/hazardalerts/diesel_exhaust_hazard_alert.html.

alleviate the impact, the fire service must determine what measures can be taken to modify the current equipment and procedures to address the health and safety risks associated with exposure. Firefighters are exposed to numerous contaminants including biological, chemical, physical, and radiological material throughout their careers. Examining how current practices are performing, for similar hazards, can indicate whether those methods can be adapted to handle the contamination of CNT. As nanotechnology continues to move forward, the examples of the past must be recognized to guide the future. The threat needs to be understood so that proper training, procedures, and regulation can be developed to limit future exposure. The past practice of managing a problem after signs and symptoms have presented in members is not an acceptable method for addressing this issue. If current practices are not performing well then future programs must not be structured along the same course. Appropriate mitigation techniques can be developed to address this exposure, as well as regulation to provide warnings of which products contain CNT. Leaders of various fire departments will then be in a better position to make educated decisions on how best to protect their members.

B. RESEARCH QUESTIONS

- To what extent are the exposure and pathological progression of CNT similar to those of asbestos, and what are the implications for the fire service?
- Can preventive measures be taken to minimize the impact of this emerging technology on those who are exposed to it?
- Can current decontamination and prevention practices in the fire service be modified and adapted to combat the hazard of CNT?

The thesis identifies the threat and proposes practices that can minimize exposure to that threat. An analysis of existing hazards provides an indication of what practices may be most useful in the future and how to improve on those not as effective. By evaluating current methods of prevention and decontamination for similar hazards, and determining the efficacy of those methods, the solutions proposed can be tailored to the specific needs of this new technology.

C. RESEARCH DESIGN

The focus of this thesis is on the threat to the fire service from exposure to CNT as a byproduct of combustion. Firefighters are exposed to numerous chemicals in the toxic environment of a structural fire. As CNT become incorporated more and more into everyday products, firefighters will face an increased exposure to them. Issues associated with the natural degradation of material containing CNT are not addressed in this paper. Various experiments have been designed to understand what impact CNT exposure may have on industrial workers who handle the material, or to determine the environmental impact of the life cycle of material containing CNT. While these studies are important and the results are useful for policy implementation and regulation, it is beyond the scope of this thesis. The intent of this thesis is to bring awareness to the possibility of a serious health hazard facing the fire service. While the implications of exposure to nanotechnology are being explored for the workers handling the material, firefighters exposure is currently uncontrolled and the severity largely unknown. This thesis gives guidance for the development of measures that can be taken to ensure the safety of the firefighters exposed to this material.

Nanotechnology is a rapidly emerging technology with exciting applications. The possible accompanying health threats, however, are not yet fully realized. This thesis explores the literature on the various experiments associated with exposure to CNT, one of the most prolific uses of nanotechnology. These experiments are designed to determine what effects exposure to CNT has on the body by using both *in vivo*, as well as *in vitro* experiments, with an emphasis on the effects of exposure to CNT via inhalation. Some experiments are examined to determine what detrimental effects CNT can have when firefighters are exposed to them. Still others are examined to compare the documented effects of asbestos exposure to that of CNT, based on the strong correlation between the physical structure of asbestos and CNT fibers. Finally, diesel exhaust studies are examined to identify how incidentally occurring CNT have infiltrated the lungs of the general population at large, via particulate matter suspended in outside air and what effect that has had.

This thesis is based on case study analysis, primarily with some quantitative analysis of risk and decision-making. After looking at the experimental data, two cases are examined to gain an understanding of how difficult it is to acquire an awareness of an emerging dilemma. The first case study relates the threat of CNT exposure to the threat of asbestos in the past. This comparison is relevant, as asbestos toxicology is well documented. Asbestos was used extensively in the late 1800s during the industrial revolution to provide fire resistivity to everything from concrete to clothing.[24] It was incorporated into a wide variety of industries despite indications that asbestos had detrimental effects on the health of those exposed. At the height of its use in 1973, 803,000 metric tons were consumed in the United States alone.[25] That same year, the first lawsuit was filed on behalf of Clarence Borel against manufacturers of asbestos products to hold them liable for "injuries caused by its products."[26] It took more than 100 years of study, countless victims of mesothelioma, and multiple lawsuits to understand fully the devastating impact that this mineral has on the human body.[27] Asbestos was used so extensively that despite being banned in 50 different countries, approximately 43,000 deaths annually still occur worldwide from mesothelioma.[28] This case study demonstrates the devastating effect of moving forward with technology without fully understanding the possible consequences. It also highlights how devastating CNT can be if they do indeed act like asbestos fibers inside the human body. Thus, the asbestos case can be considered an "analogous case," defined by experiments such as the one performed by Poland et al., in which they injected CNT into mice and compared the

[24] "Asbestos Products," Asbestos, accessed February 15, 2017, https://www.asbestos.com/products/.

[25] Ibid.

[26] "Asbestos," Asbestos, accessed January 9, 2017, https://www.asbestos.com/asbestos/.

[27] Ibid.

[28] Leslie Stayner, Laura S. Welch, and Richard Lemen, "The Worldwide Pandemic of Asbestos-Related Diseases," *Annual Review of Public Health* 34, no. 1 (March 18, 2013): 4.1–4.12, https://doi.org/10.1146/annurev-publhealth-031811-124704.

reaction to that of exposure to asbestos fibers.[29] The results of the study indicated that exposure to long-term CNT causes asbestos-like inflammation and scarring of the lining surrounding the organs.[30] As very little guidance is available for the fire service regarding CNT, it is prudent to look to asbestos for insight.

The second case study examines how diesel exhaust exposure was studied and handled in the fire service. When the fire service started using diesel-fueled apparatus, little thought was put into the associated threats to firefighters. The new diesel powered rigs were installed in firehouses without any modifications made to address the infiltration of exhaust fumes and diesel particulates throughout the living quarters of the employees.[31] Then, as the fire service started to become aware that diesel exhaust could be harmful, it began to look at the various factors involved. Studies were performed to determine what the harmful effects were on firefighters and what the exposure routes were.[32] These studies lead to recommendations for various mitigation techniques, such as emission control systems, to remove the exhaust, as well as specific engineering codes associated with the layout and construction of new firehouses with an emphasis on limiting exposure.[33] While the fire service started transitioning apparatus to diesel power in the late 1960s, the World Health Organization (WHO) did not classify diesel exhaust as a Group 1 carcinogen until 2012.[34] This case study demonstrates how a threat that seems so apparent in hindsight can be deliberated on for far too long. The institutional

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[29] Craig A. Poland et al., “Carbon Nanotubes Introduced into the Abdominal Cavity of Mice Show Asbestos-like Pathogenicity in a Pilot Study,” *Nature Nanotechnology* 3, no. 7 (May 20, 2008): 423, https://doi.org/10.1038/nnano.2008.111.

[30] Ibid., 424–425.

[31] Thomas Garrity, *Does Exposure to Diesel Emissions Increase Cancer Mortality Risk For Philadelphia Firefighters?* (Emmitsburg, MD: National Fire Academy, 1998), 1, http://citeseerx.ist. psu.edu/viewdoc/download?doi=10.1.1.609.664&rep=rep1&type=pdf.

[32] John R. Froines et al., “Exposure of Firefighters to Diesel Emissions in Fire Stations,” *Am. Ind. Hyg. Assoc. J.; (United States)* 48, no. 3 (March 1, 1987): 202, https://doi.org/10.1080/1529866879138 4634.

[33] Federal Emergency Management Agency and United States Fire Administration, *Safety and Health Considerations for the Design of Fire and Emergency Medical Services Stations* (Washington, DC and Emmitsburg, MD: Federal Emergency Management Agency and United States Fire Administration, 1997), 65, https://www.usfa.fema.gov/downloads/pdf/publications/fa-168.pdf.

[34] International Agency for Research on Cancer (IARC), *IARC: Diesel Engine Exhaust Carcinogenic,* Press Release No. 213 (Geneva, Switzerland: World Health Organization (WHO), 2012), 1, http://www.ia rc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf.

ignorance perpetuated during that debate must be overcome before the threat can be identified and acknowledged, and effective measures established to manage the hazard.

The majority of current studies focus on what would be a reasonable exposure to CNT from handling the product at the manufacturing stage. Much like hazards in the past, the fire service is hardly considered in these studies as the emphasis is put on advancing product development over safety. As CNT become used more extensively, the fire service must examine what exposure will mean to the health of the members. This thesis brings notice to the fire service of the hazards associated with exposure to CNT. This awareness provides guidance on what studies will be necessary to appreciate the threat posed by CNT more fully and how the fire service can best participate in those studies. It can also give guidance on how the fire service should proceed to control that exposure. As the fire service continues to struggle with health issues associated with both asbestos and diesel exhaust exposure, this new risk should be anticipated.

D. LITERATURE REVIEW

This literature review examines the science behind nanomaterial so that the possible threat that this new technology poses can be understood. It also examines the similarities between exposure to fibrous-shaped CNT and asbestos. As asbestos has known health implications, such similarities can be indicative of a significant hazard. The existence of incidentally occurring CNT in diesel exhaust is then considered to identify how exposure to that particulate matter currently impacts the health of members of the fire service and the greater population at large.

1. Carbon Nanotubes

Specifically, the focus of this literature review is on the threat of inhaled CNT that can be aerosolized due to fire or explosion. The literature reveals that there is ongoing debate concerning the extent of the threat that CNT pose. Experiments, such as those performed by Wang et al. entitled, "Neoplastic-like Transformation Effect of Single-Walled and Multi-Walled Carbon Nanotubes Compared to Asbestos on Human Lung Small Airway Epithelial Cells," indicate that CNT can damage lung tissue, the interstitial space between the lungs and the outer membrane, as well as other organs in the body.[35] This study was published in 2013 in the *Journal of Nanotoxicology*. Nanotechnology is a very young field of study but it is being developed very rapidly. As such, the scientific data regarding the effects of exposure to this emerging technology is still being developed. This particular experiment was performed *in vivo* by aerosolizing CNT and exposing mice through inhalation to determine how the lungs reacted to CNT. Those results were analogous to others, which also found that CNT had detrimental physiological effects.[36] The implication for the fire service is significant because this exposure represents a new addition to the toxic environment found in a structural fire. Firefighters will find themselves dealing with this added health hazard as they are being exposed.

Still, there are questions over the extent of the harmful effects of exposure to CNT with a few studies disputing the impact on lung cells. One such experiment tested exposure to lung cells *in vitro* with limited biological impact to the cells, much as Chortarea et al. did in a study entitled "Repeated Exposure to Carbon Nanotube-based Aerosols Does Not Affect the Functional Properties of a 3D Human Epithelial Airway Model."[37] That study was published in 2015 in the *Journal of Nanotoxicology*. It represents a modeling type of experiment where human lung cells are kept viable outside of the lungs but in an environment designed to represent the lungs. The findings in this study indicate that CNT had limited effect on the cells lining the lungs.[38] The experiment looked specifically at how viable lung cells were after being exposed to CNT. The limitation of this experiment is that the cells are modeled in isolation, outside of the body. This type of experiment does not account for the interaction between different bodily functions. The respiratory system is a complex arrangement of organs designed to

[35] Liying Wang et al., "Neoplastic-like Transformation Effect of Single-Walled and Multi-Walled Carbon Nanotubes Compared to Asbestos on Human Lung Small Airway Epithelial Cells," *Nanotoxicology* 8, no. 5 (August 2014): 486, https://doi.org/10.3109/17435390.2013.801089.

[36] Mercer et al., "Pulmonary Fibrotic Response to Aspiration of Multi-Walled Carbon Nanotubes," 15.

[37] Savvina Chortarea et al., "Repeated Exposure to Carbon Nanotube-Based Aerosols Does Not Affect the Functional Properties of a 3D Human Epithelial Airway Model," *Nanotoxicology* 9, no. 8 (November 17, 2015): 983–93, https://doi.org/10.3109/17435390.2014.993344.

[38] Ibid.

exchange oxygen and carbon dioxide while keeping the system clean and running smoothly. The effects on the system as a whole should be looked at to appreciate how the body will react.

Another feature that sustains the debate is the shape of the material. Single CNT resemble thin, needle-like fibers, with dimensions similar to long asbestos fibers. Samples taken when CNT are aerosolized, though, can be bent and tangled. They can bunch up and form agglomerates due to the attractive Van der Waals forces that act along the surface.[39] Those attractive forces act on the molecular level to clump the fibers together. The shape of the particles can alter how effective the immune system is at clearing them from the body. As Figure 1 demonstrates, when CNT bunch up, they can be enclosed by white blood cells and successfully cleared. The longer individual particles, however, cannot be sufficiently managed and lead to inflammation.

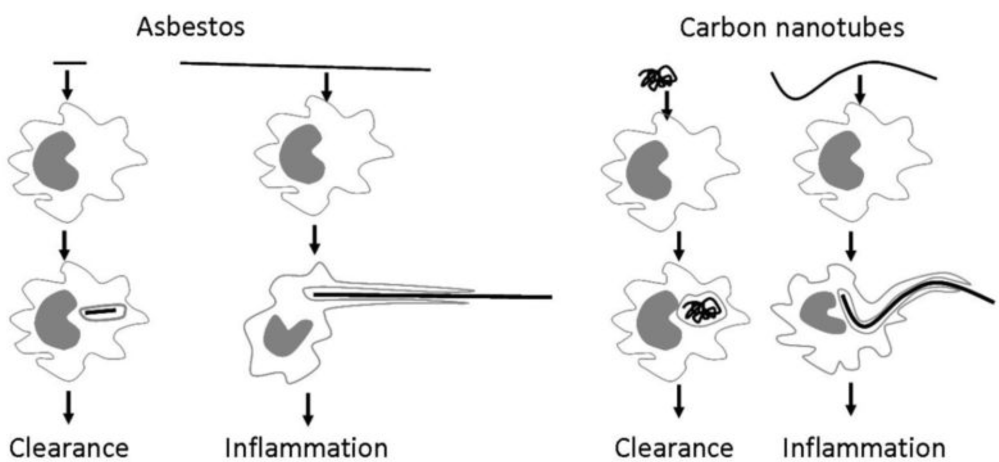

Figure 1. Length Dependency for Cell Inflammation[40]

Thus, while CNT can at times display physical characteristics of asbestos particles, at other times, they can bunch up and present as cables or ropes stuck together.

[39] Donaldson et al., *The Toxicology of Carbon Nanotubes*, 68.

[40] Source: Ken Donaldson et al., "Asbestos, Carbon Nanotubes and the Pleural Mesothelium: A Review of the Hypothesis Regarding the Role of Long Fibre Retention in the Parietal Pleura, Inflammation and Mesothelioma," *Particle and Fibre Toxicology* 7, no. 5 (March 22, 2010): 4, https://doi.org/10.1186/1743-8977-7-5.

It has been demonstrated that CNT cause disease based on the relationship between the length of fibers inhaled and the inability of the body to clear or dissolve them.[41] When the fibers bunch up together, they do not distribute evenly across the lining of the lungs and no longer interact as individual fibers do, which may reduce the impact of a given exposure. For experiments to obtain a more accurate illustration of the interaction between CNT and the various cell types in the lungs, it would be more useful to combine cultures of inflammatory cells and mesothelial cells together.[42] That combination can demonstrate more accurately how the cells are reacting in concert, to the exposure.

2. Correlation to Asbestos

The close physical resemblance of some long CNT and asbestos is concerning given the known effects of asbestos. Like CNT, asbestos was used extensively in a variety of applications including construction material, automobile parts, and textiles. Many considered it a "miracle mineral" until the first half of the 20th century when mounting evidence indicated that exposure to asbestos caused scarring of lung tissue.[43] Unlike the emerging technology of CNT, however, asbestos exposure has been well documented in both laboratory modeling, as well as human studies. A study performed in 1999 by Dr. Nabil Al Jarad, and published in the *Journal of the Royal College of Physicians of London* regarding asbestos-related disease examined the pathology of asbestos exposure using high-resolution computed tomography (CT) scans and chest radiographs of exposed individuals.[44] It was determined that asbestos exposure resulted in a number of diseases including asbestosis, lung cancer, and mesothelioma.[45] Such studies over the decades resulted in the classification of asbestos as a known human

[41] Donaldson et al., *The Toxicology of Carbon Nanotubes*, 69.

[42] Ibid., 203.

[43] Nick Walker, "How Asbestos Went from a Miracle Mineral to a Medical Disaster," Canadian Geographic, December 15, 2016, https://www.canadiangeographic.ca/article/how-asbestos-went-miracle-mineral-medical-disaster.

[44] Nabil Al Jarad, "Asbestos-Related Disease," 1999, http://www.clinmed.rcpjournal.org/content/jroy collphys/33/6/532.full.pdf+html.

[45] Ibid.

carcinogen by the WHO.[46] While the literature on the reaction to CNT is currently being developed through animal trials and laboratory modeling, asbestos pathology has been extensively documented all the way through human studies. Given the similarities between the two, and the consequences demonstrated from the protracted analyses of asbestos, it is important to develop precautionary measures while the investigation into CNT continues.

3. Correlation to Diesel Exhaust

Much like the long path asbestos took from its initial use to its ultimate classification as a human carcinogen, another health hazard has had protracted lethal consequences for the fire service. Exposure to diesel exhaust and diesel particulate matter has progressed from being viewed as a tolerated nuisance associated with diesel engines to a Group 1 carcinogen according to the WHO.[47] A substance may be placed in a Group 1 category "when evidence of carcinogenicity in humans is less than sufficient but there is sufficient evidence of carcinogenicity in experimental animals and strong evidence in exposed humans that the agent acts through a relevant mechanism of carcinogenicity."[48] The fire service was slow to recognize the dangers of particulate matter in diesel exhaust as diesel-powered apparatus were incorporated into firehouses in the early 1960s. The literature published on the effects of diesel exhaust on firefighters began with studies, such as the one by John Froines et al. entitled "Exposure of Firefighters to Diesel Emissions in Fire Stations."[49] This study was published in the *American Industrial Hygiene Association Journal* in 1987, approximately 20 years after numerous fire departments began switching over to diesel-powered vehicles. The study evaluated the rate of exposure to particulates from diesel engines that firefighters from Los Angeles, Boston, and New York City endured.[50] It was one of the most extensive studies done and

46 "Asbestos and Cancer Risk," American Cancer Society, accessed June 27, 2017, https://www.cancer.org/cancer/cancer-causes/asbestos.

47 International Agency for Research on Cancer (IARC), *IARC: Diesel Engine Exhaust Carcinogenic*.

48 Ibid.

49 Froines et al., "Exposure of Firefighters to Diesel Emissions in Fire Stations."

50 Ibid.

provided data on exposure rates that ultimately led to the development of new standards for air handling controls inside firehouses.

Despite the known carcinogenic impact of diesel exhaust exposure, measures to protect firefighters remain inadequate. A current study concerning the effects of diesel exhaust exposure on firefighters demonstrates that it is still an ongoing problem. The study involves Dr. Glorian Sorensen and Dr. Emily Sparer and is funded by the Dana-Farber Cancer Institute.[51] Data on chronic exposure rates to diesel exhaust inside a sample set of Boston firehouses is analyzed to determine why firefighters are still being diagnosed with particular types of cancer at higher rates than normal: multiple myeloma, non-Hodgkin lymphoma, prostate cancer, gastrointestinal cancer, and lung cancer.[52] The toxic effects of exposure continue to impact the fire service even as the hazard is being investigated. An examination of this danger demonstrates how difficult it is to safeguard firefighters while an ongoing threat is being explored. It also gives direction on how the fire service can influence the process by requiring effective labeling and hazard warnings on products.

The literature review on CNT exposure reveals that the threat is not exclusive to the fire service. The release of CNT due to incidental or catastrophic events has the potential to affect an even greater population. CNT needs three things to form: a heat source, a carbon source, and metallic particles.[53] The toxic environment around the World Trade Center (WTC) in 2001 possessed all the needed ingredients. In a study entitled "Lung Disease in World Trade Center Responders Exposed to Dust and Smoke," Wu et al., examined a sample of people exposed to the atmosphere around the WTC in 2001, which included first responders, construction workers, cleaning personnel, and

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[51] "Firefighters and Cancer: Dana-Farber Scientists Investigate," *Dana-Farber Cancer Institute* (blog), February 27, 2017, http://blog.dana-farber.org/insight/2017/02/firefighters-and-cancer-dana-farber-scientists-investigate/.

[52] Ibid.

[53] Jack Howard, "Flame Synthesis of Single-Walled Carbon Nanotubes," *Carbon*, 2295, accessed November 9, 2017, http://www.academia.edu/4454055/Flame_synthesis_of_single-walled_carbon_nanotubes.

people who lived in Lower Manhattan at the time.[54] The study confirmed an association between exposure to the atmosphere around the WTC and lung disease along the lining of the lungs. They discovered the presence of CNT of various lengths and sizes in the lung tissue of individuals exposed to WTC dust, as well as various dust samples.[55] A follow up study performed by Barna, Judson, and Thomassen discussed the correlation between the laboratory findings regarding the detrimental effects of CNT exposure with evidence of an accumulation of inflammatory cells known as granulomatous disease in first responders.[56] These studies indicate that exposure to CNT in the uncontrolled environment of a fire is a possibility and that the exposure will have harmful consequences. As concern for the health implication of exposure to CNT increases, researchers are reexamining various possible exposure vectors.

Researchers are specifically questioning how air quality is affected by CNT in an urban setting. A technical paper written by Jung et al. entitled "Carbon Nanotubes among Diesel Exhaust Particles: Real Samples or Contaminants?" examined multiple samples of diesel exhaust and determined that CNT were present in the particulate matter of each sample.[57] The results of that study suggest that CNT are much more pervasive in air pollution than anticipated. In fact, an analysis of the metallic nanoparticles in the atmosphere determined that road vehicle emissions represent the primarily source.[58] That study raises the question then of how CNT contribute to the damaging effects of air pollution. In a study designed to answer that question, researchers examined the particulate matter inside the lungs of a sample of asthmatic children in Paris.[59] The

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54 Maoxin Wu et al., "Case Report: Lung Disease in World Trade Center Responders Exposed to Dust and Smoke: Carbon Nanotubes Found in the Lungs of World Trade Center Patients and Dust Samples," *Environmental Health Perspectives* 118, no. 4 (April 2010): 499, https://doi.org/10.1289/ehp.0901159.

55 Ibid.

56 Barna, Judson, and Thomassen, "Carbon Nanotubes and Chronic Granulomatous Disease," 508.

57 Jung et al., "Carbon Nanotubes among Diesel Exhaust Particles."

58 Paul Sanderson, Juana Maria Delgado Saborit, and Roy Harrison, "A Review of Chemical and Physical Characterisation of Atmospheric Metallic Nanoparticles," *Atmospheric Environment* 94 (September 1, 2014): 355, https://doi.org/10.1016/j.atmosenv.2014.05.023.

59 Jelena Kolosnjaj-Tabi et al., "Anthropogenic Carbon Nanotubes Found in the Airways of Parisian Children," *EBioMedicine* 2, no. 11 (November 1, 2015): 1698, https://doi.org/10.1016/j.ebiom.2015.10.012.

findings revealed the presence of CNT in the lungs of each of the children suffering from asthma. The structural composition of the CNT were then compared to ones found in dust and exhaust samples taken at various locations throughout the city. The similarities between them suggested that the general population is consistently exposed to CNT in the form of particulate matter in the ambient air.[60] These results have major implications for the study of urban air quality management in the future.

The results of the various studies reviewed demonstrate that the concern for the health hazards associated with nanotechnology is reasonable. The inhalation of CNT is particularly disturbing given the indications of the body's reaction. This is noteworthy in light of the evidence that combustion generated CNT are prevalent in the particulate matter found in diesel exhaust, which is a major contributor to global air pollution. The similarities between the effects of exposure to CNT and asbestos, a known hazard, indicate that this threat is a significant one. The fire service in particular has suffered so extensively due to the widespread use of asbestos that this connection should serve as a warning sign. The association between CNT and diesel exhaust is another warning sign that must be acknowledged. The fire service has been significantly affected through exposure to both asbestos and diesel exhaust and must use the lessons learned from those experiences to manage this analogous threat. Just as other emerging threats have been exposed, acknowledged, and finally addressed in the past, this new threat needs to be investigated further and measures taken to ensure the health of everyone who comes in contact with it.

[60] Kolosnjaj-Tabi et al., "Anthropogenic Carbon Nanotubes Found in the Airways of Parisian Children," 1701.

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II. ASBESTOS

As researchers struggle to understand the possible health risks associated with nanotechnology, the fire service must look to past examples for guidance. Given the indications that exposure to CNT may cause reactions similar to that of asbestos fibers in the lungs, it is useful to examine how devastating asbestos exposure has been and how inadequately that threat was handled. History has demonstrated that caution must be exercised before another "miracle" technology is incorporated into everyday life, much as asbestos was in the past.

This chapter examines the threat that asbestos presents and how that threat has affected both the general population, as well as the fire service. First, the different types of asbestos are identified and the region from which they come. The various uses for asbestos are considered along with the early indications that the material may be harmful. Studies are then examined that began to demonstrate the harmful effects that asbestos was having on those exposed. While the evidence was mounting, the demand for the mineral continued to grow. The numerous regulations put into place over the years to limit exposure are identified along with the competing economic factors that influenced the continued use of asbestos. The health threat is then considered as it relates to the fire service and how the hazard continues to harm firefighters to this very day.

A. MATERIAL BACKGROUND

Asbestos is a natural mineral fiber that exists in six different varieties in rock and soil. The most common are chrysotile, amosite, and crocidolite. Chrysotile, or white, asbestos occurs in large deposits in Russia, the United States, and Canada.[61] It has long, curled fibers that are not as sharp as the other forms, and is the variety of asbestos most often used for industrial purposes.[62] The other two types of asbestos are found primarily

[61] IARC Working Group, *Arsenic, Metals, Fibres, and Dusts*, Volume 100C A Review of Human Carcinogens (Lyon, France: International Agency for Research on Cancer, 2012), 222, http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf#page=233.

[62] "3 Types of Asbestos Fibers," *Asbestos* (blog), 12, accessed August 8, 2017, http://www.asbestosnetwork.com/blog/2015/06/3-types-of-asbestos-fibers.shtml.

in Africa and Australia. Amosite is a brown asbestos with long, jagged, needle-like fibers, and crocidolite is a blue asbestos generally considered the most dangerous.[63] While there are six different varieties of asbestos, these three forms are the most prevalent, and therefore, the ones that the fire service is most likely to be exposed to, with chrysotile representing more than 99 percent of current worldwide production.[64]

The first use of asbestos can be traced to the ancient Egyptians and Greeks, who wove the material into garments and incorporated it into the wicks of lamps. In the late 1800s during the Industrial Revolution, however, is when asbestos was most extensively employed to provide fire resistivity and structural reinforcement to everything from concrete to clothing. It is a cheap, abundant, and durable material with amazing fireproofing properties.[65] These characteristics made it ideal for the construction and manufacturing industries. Asbestos began to be utilized in everyday consumer items, such as roofing and floor tiles, automotive parts, insulation, and textiles, including theater curtains and protective gear for firefighting. The material was incorporated in building construction throughout the United States with extensive use in military applications, especially ships. By 1973, at the height of its use in the United States, approximately 803,000 metric tons of asbestos were being consumed annually.[66] Such extensive consumption resulted in exposure to miners, manufacturing workers, and ultimately, consumers of asbestos-containing materials.

B. PATHOLOGY OF ASBESTOS

While asbestos was becoming more and more prevalent, early indications showed that exposure to the material was dangerous. As far back as 1906 in London, Dr. M. Murray at the Charing Cross Hospital testified to the first recorded death of a worker

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[63] "3 Types of Asbestos Fibers," 12,

[64] Stayner, Welch, and Lemen, "The Worldwide Pandemic of Asbestos-Related Diseases," 4.2.

[65] "Asbestos Products."

[66] "Asbestos Exposure and Cancer Risk," National Cancer Institute, accessed November 9, 2017, https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/asbestos/asbestos-fact-sheet.

from exposure to asbestos.[67] In this case, the autopsy revealed that the lungs of the worker were "extremely tough and fibrous, especially in the lower part."[68] This testimony represented one of the first documented cases connecting asbestos dust to fibrosis of the lungs. A few years later, in 1924, Dr. J. M. Beattie published results of an autopsy performed on a 33-year-old woman who died of lung fibrosis after working in asbestos textile factories for 20 years.[69] This report was significant in that the autopsy and published x-rays of the patient confirmed what Dr. Beattie had recognized using experimental results with guinea pigs—that asbestos dust caused fibrosis of the lungs.[70] Doctors from areas where asbestos was being manufactured had long suspected asbestos dust was the cause of the chronic bronchitis and fibrosis that afflicted their patients.

As researchers continued to study the health effects of asbestos, manufacturers continued to produce products containing asbestos without any health warnings for workers or labeling for consumers. One of the largest of these companies, the Johns-Manville Company, went so far as to commission a study in 1936 on the hazards of asbestos.[71] The results of that study, performed by the Saranac Laboratories in upstate New York, were noted in a report sent by Dr. Gardner to company executive Vandiver Brown. In the report, which was kept confidential by Johns-Manville, Dr. Gardner noted that mice exposed to long-fiber asbestos had an over 81 percent incidence of pulmonary cancer.[72] He went on to state, "The question of cancer susceptibility now seems more significant than I had previously imagined."[73] Those findings were kept confidential until

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[67] Herbert Louis Samuel and Great Britain, Home Office, Committee on Compensation for Industrial Diseases, …*Report of the Departmental Committee on Compensation for Industrial Diseases [with Minutes of Evidence, Appendices, and Index]* (London: Printed for H. M. Stationery off., by Wyman and Sons, limited, 1907), http://archive.org/details/cu31924002289290.

[68] Ibid.

[69] W. E. Cooke, "Fibrosis of the Lungs Due to the Inhalation of Asbestos Dust," *Br Med J*, 2, no. 3317 (July 26, 1924): 147, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2304688/.

[70] Ibid.

[71] "Asbestos Industry Suppressed and Altered Medical Research," Mesothelioma, accessed November 10, 2017, http://mesothelioma.co/asbestos/the-asbestos-industry-cover-up/asbestos-industry-suppressed-and-altered-medical-research/.

[72] Barry I. Castleman and Stephen L. Berger, *Asbestos: Medical and Legal Aspects* (New York: Aspen Publishers, 2005), 49–50.

[73] Ibid., 50.

some 15 years later when a revised report was issued that censored any reference to cancer and to the results of tumor occurrence in the experiments. The asbestos industry was actively suppressing evidence while continuing to profit from asbestos use despite the lethal consequences of that use.

Another study performed by Dr. Gardner at the Saranac Laboratories seemed to substantiate the claims of a connection between asbestos exposure and lung damage. That study was designed to determine what effect dust produced from a newly developed asbestos-based house insulation developed by Owens-Illinois Glass Company would have when inhaled by mice.[74] The study was performed in the early 1940s and the results indicated that the material was "capable of producing asbestosis and must be regarded as a potentially hazardous material"[75] Again, the report was the property of the company and remained unpublished. Despite those findings, asbestos insulation continued to be manufactured and sold without any warnings to workers or consumers up until Occupational Safety and Health Administration (OSHA) banned it in 1973.[76] While the destructive effects of asbestos exposure continued to be revealed, the industry continued to develop more asbestos containing products. It was not until the research moved from animal trials to human studies that the warnings became undeniable. In 1964, Selikoff, Churg, and Hammond published a study that linked mesothelioma and cancer with exposure to asbestos.[77] This extensive study examined 632 insulation workers over approximately 20 years, with startling results. The authors found that 45 workers died of cancer of the lung or pleura. This number represented an increase of 6.8 times higher than the general male population.[78] The connection to cancer indicated that the effects of asbestos exposure went beyond the initial belief that it only caused fibrosis of the lungs.

Those studies were raising an alarm about the destructive health effects of asbestos exposure that could not be ignored. In an article published by Kamp and

[74] "Asbestos Industry Suppressed and Altered Medical Research."

[75] Ibid.

[76] Ibid.

[77] Irving J. Selikoff, Jacob Churg, and E. Cuyler Hammond, "Asbestos Exposure and Neoplasia," *JAMA* 188 (April 6, 1964): 94.

[78] Ibid., 93.

Weitzman, they noted, “Asbestos causes progressive pulmonary fibrosis (asbestosis), pleural disease (effusion and pleural plaques), and malignancies such as bronchogenic carcinoma and malignant mesothelioma.”[79] Those conclusions were based on decades of observation of patients who presented with various lung ailments, as well as *in vitro* and *in vivo* experiments. The *in vitro* experiments demonstrated the cellular and molecular effects of exposure to asbestos fibers while the *in vivo* experiments measured the biochemical changes related to cell proliferation due to inhalation.[80] The medical data revealed the devastating consequences of incorporating asbestos into so many manufactured products.

C. ASBESTOS LITIGATION

As the medical evidence continued to accumulate, the litigation followed. It began in 1973 with the first personal injury lawsuit brought by a worker against the manufacturers of asbestos products. The Fifth Circuit Court of Appeals in Borel V. Fibreboard “found asbestos manufacturers strictly liable to workers injured as a result of exposure to their product.”[81] A flood of litigation against asbestos manufacturers followed the ruling by the court. A decade later, over 20,000 lawsuits were claiming injuries from exposure to asbestos.[82] These cases were an indication of the extent of injury that asbestos exposure was causing and that continues to cause. The RAND Corporation projects that the future course of litigation can result in from one to two million claimants with an associated cost estimated between $200 and $265 billion.[83] The asbestos crisis had progressed to a point at which researchers were now able to include human studies in the database of evidence.

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[79] David W. Kamp and Sigmund A. Weitzman, “The Molecular Basis of Asbestos Induced Lung Injury,” *Thorax* 54, no. 7 (July 1, 1999): 638, https://doi.org/10.1136/thx.54.7.638.

[80] Timothy R. Quinlan et al., “Patterns of Inflammation, Cell Proliferation, and Related Gene Expression in Lung after Inhalation of Chrysotile Asbestos,” *American Journal of Pathology* 147, no. 3 (September 1995): 733, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1870980/.

[81] Stephen J. Carroll et al., *Asbestos Litigation* (Santa Monica: RAND, 2005), 2.

[82] Ibid.

[83] Ibid., 77.

As the lethal effects of asbestos exposure continued to be revealed, so did the demand for the material. Global demand for asbestos reached its pinnacle in 1977, when some 25 countries were still producing as much as 4.8 million metric tons annually.[84] This continued demand was due in part to the insidious nature of asbestos exposure, as the associated pathology can sometimes take decades to develop. As Kamp and Weisman indicated, "asbestos related diseases typically occur after a 15–40 year latency period following initial fiber exposure."[85] That delayed reaction brought into question the correlation between asbestos dust and medical conditions, such as mesothelioma and cancer for decades.

D. REGULATORY CONTROLS

The litigation, supported by the medical findings, forced the government to begin enacting regulatory controls for the use of asbestos. The asbestos industry, however, pushed back and the resulting regulation allowed the manufacturing of asbestos products to continue. In 1989, the Environmental Protection Agency (EPA) issued a final ruling under the Toxic Substance Control Act (TSCA) that prohibited, at staged intervals, "the future manufacture, importation, processing, and distribution in commerce of asbestos in almost all products, as identified in the rule."[86] This ruling effectively banned most asbestos-containing products, but it was quickly overturned in 1991 by the Fifth Circuit Court of Appeals in New Orleans, which ruled that only products no longer being manufactured, imported, or processed when the rule was issued were subject to the ban.[87] The regulation did retain a ban on "new uses" of asbestos in products that did not already contain asbestos.[88] The court left everything currently being manufactured, imported, or

[84] "The History of Asbestos," Asbestos, accessed August 7, 2017, https://www.asbestos.com/asbestos/history/.

[85] Kamp and Weitzman, "The Molecular Basis of Asbestos Induced Lung Injury," 638.

[86] "United States—Asbestos; Manufacture, Importation, Processing, and Distribution in Commerce Prohibitions Rule (40 CFR Part 763)," Federal Register 54, no. 132 (July 12, 1989): 29460, http://www.ilo.org/dyn/natlex/natlex4.detail?p_lang=&p_isn=8071.

[87] "Federal Register, Volume 59 Issue 123 (Tuesday, June 28, 1994)," U.S. Government Publishing Office, accessed September 27, 2017, https://www.gpo.gov/fdsys/pkg/FR-1994-06-28/html/94-15676.htm.

[88] "United States—Asbestos; Manufacture, Importation, Processing, and Distribution in Commerce Prohibitions Rule (40 CFR Part 763)," 29500.

processed at the time unrestricted by the ruling. While this ruling may seem inadequate, it does mean that materials included in the ban cannot be repurposed for use in new products.

The economic interests were in competition with health and safety interests while asbestos continued to be incorporated in current products. The EPA attempted to conduct a cost/benefit analysis of asbestos use to justify a more inclusive ban. The analysis struggled with such issues as how to quantify health risks, the cost-effectiveness of warning labels, and the possibility of substitutes for asbestos being just as harmful. In the end, the EPA managed to ban the following six categories of asbestos-containing products:

- Felt flooring
- Commercial paper
- Specialty paper
- Rollboard
- Corrugated paper
- Spray applied asbestos insulation[89]

Along with the ban of those particular items, the EPA, as well as OSHA did strictly regulate the handling of material containing asbestos. Stringent remediation restrictions were created and OSHA established a permissible exposure limit (PEL) of only 0.1 fiber per cubic centimeter of air in an 8-hour weighted average.[90] This PEL regulated the concentration of asbestos fibers in the air that a worker would be exposed to during an 8-hour workday. The difficulty is that asbestos continues to be used in the United States despite OSHA's warning that "asbestos exposures as short in duration as a

[89] "U.S. Federal Bans on Asbestos," Environmental Protection Agency, accessed August 7, 2017, https://www.epa.gov/asbestos/us-federal-bans-asbestos.

[90] "Asbestos—1910.1001," Occupational Safety and Health Administration, accessed August 7, 2017, https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9995.

few days have caused mesothelioma in humans."[91] With such an extremely small exposure window causing that kind of damage, it seems alarming that asbestos has not been banned completely from use.

In fact, asbestos is currently banned in 56 countries worldwide with the notable exception of China, Russia, India, Canada, and the United States.[92] While the worldwide use of asbestos has declined, emerging markets' demand for the economical and resilient construction material has actually increased, with over 70% of all extracted asbestos being utilized in Eastern Europe and Asia.[93] As stated earlier, economic forces often compete against effective regulation to the detriment of those exposed to the material. That persistent exposure will result in more deaths due to asbestosis and mesothelioma for decades to come.

It has been shown that lung afflictions resulting from asbestos exposure take years to manifest. The United States has ceased mining asbestos since 2002 and reduced the import of raw asbestos from a peak of 718,000 metric tons in 1973 to 2,000 metric tons in 2006.[94] Yet despite those restrictions and the determination by NIOSH in 1970 that asbestos fibers cause cancer and asbestosis, deaths in the United States have continued to rise for decades.[95] As Figure 2 demonstrates, over 1,200 deaths associated with asbestos exposure occurred in 2014 in the United States alone. This number is a clear indication of just how devastating and largely mishandled this hazard has been.

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[91] "Safety and Health Topics," Occupational Safety and Health Administration, accessed August 8, 2017, https://www.osha.gov/SLTC/asbestos/#4.

[92] "What Countries Have Banned Asbestos Use?," *Asbestos Network* (blog), September 23, 2015, http://www.asbestosnetwork.com/blog/2015/09/what-countries-have-banned-asbestos-use.shtml.

[93] "NIOSH Publications and Products—Current Intelligence Bulletin 62: Asbestos Fibers and Other Elongate Mineral Particles: State of the Science and Roadmap for Research," Centers for Disease Control and Prevention, 10, accessed August 8, 2017, https://www.cdc.gov/niosh/docs/2011-159/.

[94] Ibid., 9.

[95] Ibid., 5.

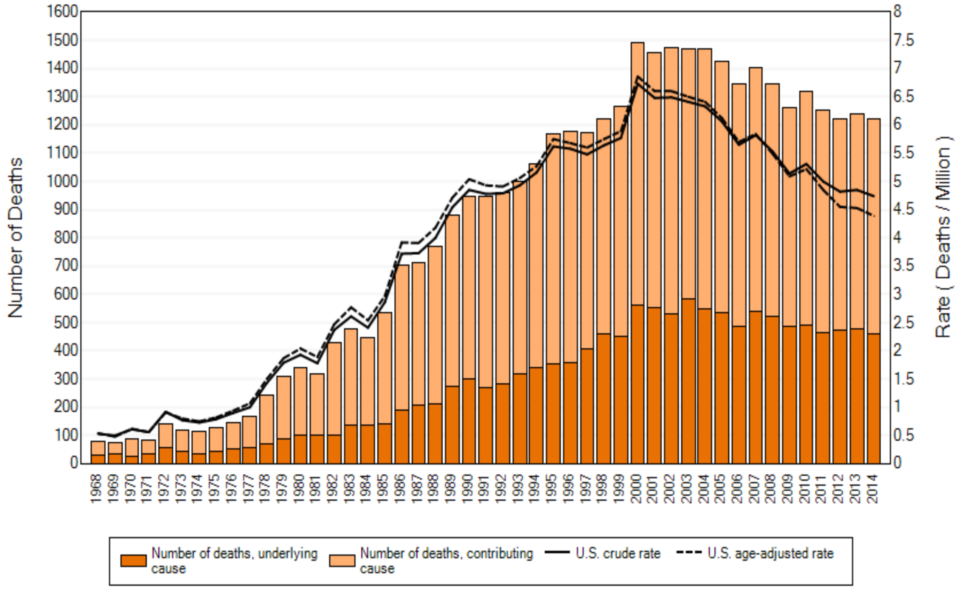

Figure 2. Asbestosis: Number of Deaths, U.S. Residents Age 15 and Over, 1968–2014[96]

While the death rate in the United States is significant, approximately 43,000 deaths occur annually from mesothelioma worldwide.[97] These deaths are a stark reminder that nothing can be taken for granted when it comes to threats to human health. A delayed and ineffective response to this particular threat is still having devastating effects globally. Clearly, the threat of asbestos exposure has been seriously mishandled. The competing interests of profits against health and safety have enabled lawmakers to acquiesce to economic interests when it came to regulation. This acquiescence has been especially detrimental in the case of firefighters who have been exposed to asbestos over the years.

96 Source: "Asbestosis: Number of Deaths, Crude and Age-Adjusted Death Rates, U.S. Residents Age 15 and Over, 1968–2010," Centers for Disease Control and Prevention, accessed August 8, 2017, https://wwwn.cdc.gov/eworld/Data/Asbestosis_Number_of_deaths_crude_and_age-adjusted_death_rates_US_residents_age_15_and_over_19682010/748.

97 Stayner, Welch, and Lemen, "The Worldwide Pandemic of Asbestos-Related Diseases."

E. IMPACT ON THE FIRE SERVICE

Firefighters have been exposed to asbestos for years as they break open walls and ceilings during operations. Extensive studies have been done to determine what the effect of that exposure has been. One of the first studies examined 550 firefighters from New York City at the Mount Sinai School of Medicine. The study examined firefighters who worked in the city during the 1960s and accounted for other possible exposure vectors, such as previous employment. The study by Markowitz et al. determined "fire fighters are at risk for asbestos-induced interstitial pulmonary fibrosis and pleural fibrosis independent of any exposure to asbestos outside of employment as a fire fighter."[98] The study found that nine percent of the test subjects showed a disproportional amount of thickening of lung tissue than would be expected in the general population.[99] This study was careful to eliminate subjects who might have been affected by other sources of asbestos outside firefighting. The overall conclusion reached by Markowitz et al. was that "It is likely that exposure to asbestos experienced during or after fighting a fire, particularly during the overhaul phase of the fire, represents the most important source of asbestos exposure."[100] The overhaul phase represents an especially vulnerable time for firefighter exposure as the firefighters open up the structure to determine the extent of fire extension.

The results of that study prompted more in depth studies on the effects of asbestos exposure to firefighters. In a much more expansive study of almost 30,000 firefighters from San Francisco, Chicago, and Philadelphia over a 30-year period, Daniels et al. observe, "About a twofold increase in malignant mesothelioma mortality and incidence compared with the U.S. population."[101] As malignant mesothelioma is almost exclusively caused by exposure to asbestos fibers, it is clear that asbestos continues to remain a

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[98] Steven B. Markowitz et al., "Asbestos Exposure and Fire Fighting," *Annals of the New York Academy of Sciences* 643, no. 1 (December 1991): 575, https://doi.org/10.1111/j.1749-6632.1991.tb24507.x.

[99] Ibid.

[100] Ibid., 576.

[101] Robert D. Daniels et al., "Mortality and Cancer Incidence in a Pooled Cohort of U.S. Firefighters from San Francisco, Chicago and Philadelphia (1950–2009)," *Occupational and Environmental Medicine* 71, no. 6 (June 2014): 8, https://doi.org/10.1136/oemed-2013-101662.

serious threat to the fire service. Both studies indicated that exposure to asbestos has had a major impact on firefighters over the years. Given that extensive amounts of asbestos are currently in place throughout building structures, it is evident that firefighters will continue to experience a high exposure rate.

Much like asbestos in the past, CNT is a technology that currently holds a great deal of potential for improving products across a wide spectrum of industries; so much potential in fact that some feel that CNT can usher in the next industrial revolution.[102] In 2005, 54 commercially available products contained nanotechnology. By 2015, over 1,800 such products were available to the public.[103] As the science behind manufacturing and applying CNT improves, the applications will grow exponentially. The variety of products that utilize CNT will then increase and so will the avenues of exposure. Greater caution must be taken to guard against a repeat of the cavalier approach to health safety demonstrated with the use of asbestos in the past.

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[102] Wang et al., "Neoplastic-like Transformation Effect of Single-Walled and Multi-Walled Carbon Nanotubes Compared to Asbestos on Human Lung Small Airway Epithelial Cells," 485.

[103] Marina E. Vance et al., "Nanotechnology in the Real World: Redeveloping the Nanomaterial Consumer Products Inventory," *Beilstein Journal of Nanotechnology* 6, no. 1 (August 21, 2015): 1769–80, https://doi.org/10.3762/bjnano.6.181.

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III. DIESEL EXHAUST AND DIESEL PARTICULATE MATTER

Asbestos is not the only hazard that has challenged the fire service over the years. This chapter examines the damage that exposure to diesel exhaust and diesel particulate matter poses. The composition of diesel exhaust is considered and the harmful components are identified. The exposure vectors are then characterized to understand how diesel exhaust affects the general population. The chapter identifies the mechanical and regulatory measures that have been implemented to mitigate those effects. The correlation between the particulate matter (PM) in diesel exhaust and CNT is explored. Finally, the chapter examines how firefighters have been exposed to diesel exhaust to understand how difficult it is to manage such an extensive hazard.

A. MATERIAL BACKGROUND

History has demonstrated that health threats can continue for some time before being effectively addressed. Diesel exhaust exposure is one such threat that has persisted since Rudolph Diesel invented the compression-ignition diesel engine in 1892.[104] Diesel exhaust has been a major contributor to overall air pollution over the years and has created a significant global health hazard. The two dominant characteristics of that air pollution are smog and soot.[105] Both components are a product of fossil fuel combustion, with the smog resulting from a mixture of toxic chemicals interacting with sunlight to create ground level ozone, and soot consisting mostly of ultrafine particles. A major health concern with diesel exhaust entails the chemicals absorbed onto the surface of those particles.[106] Those chemicals include many irritants and known carcinogens.[107] As the particles are inhaled, the toxic chemicals are then transported onto the lung tissue.

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[104] Irina N. Krivoshto et al., "The Toxicity of Diesel Exhaust: Implications for Primary Care," *The Journal of the American Board of Family Medicine* 21, no. 1 (January 1, 2008): 55, https://doi.org/10.3122/jabfm.2008.01.070139.

[105] Jillian Mackenzie, "Air Pollution: Everything You Need to Know," NRDC, November 1, 2016, https://www.nrdc.org/stories/air-pollution-everything-you-need-know.

[106] "Diesel Exhaust: Critical Analysis of Emissions, Exposure, and Health Effects," Health Effects Institute, 5, April 1, 1995, https://www.healtheffects.org/publication/diesel-exhaust-critical-analysis-emissions-exposure-and-health-effects.

[107] Ibid.

Diesel engines provide a reliable source of energy for heavy equipment and vehicle use in industries ranging from mining, transportation, construction, maritime, and firefighting. They gained popularity because of their excellent power output, fuel economy, and durability. The exhaust from those engines, however, contains an extremely complex mixture of gases including carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, hydrocarbons, nitrates, formaldehyde, benzene, as well as diesel PM, which consists of carbon, ash, metallic abrasion particles, sulfates, and silicates.[108] Diesel exhaust is a major contributor to the overall amount of PM present in the atmosphere. As Riedl and Diaz-Sanchez note in their scientific review, "The largest single source of airborne PM from vehicles is derived from diesel exhaust."[109] As the population is exposed to that PM, the toxic chemicals that are absorbed onto the surface are incorporated into the respiratory system.

Air pollution consists of a variety of natural and man-made constituents in the atmosphere. Natural sources include windblown dust, pollen, smoke from volcanic activity, and wild land fires. Man-made sources of air pollution come mainly from the industrial use of fossil fuels. The most significant source of man-made air pollution is a result of motor vehicle traffic, particularly in cities.[110] It is not just a localized problem for the inner cities, however. It represents a greater, global threat, as Krivoshto et al. found in a review of diesel exhaust toxicity, "Diesel fuel and the products of its combustion represent one of the most common toxins to which people living in both urban and rural areas of the world are exposed."[111] While natural sources represent intermittent events, man-made sources are continuous and escalating. Global air pollution is going to intensify as industrializing nations turn to diesel fuel to provide power and transportation. That intensification will have profound global health implications.

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[108] "Diesel Exhaust/Diesel Particulate Matter."

[109] Marc Riedl and David Diaz-Sanchez, "Biology of Diesel Exhaust Effects on Respiratory Function," *The Journal of Allergy and Clinical Immunology* 115, no. 2 (February 2005): 221, https://doi.org/10.1016/j.jaci.2004.11.047.

[110] Helmut Mayer, "Air Pollution in Cities," *Atmospheric Environment* 33, no. 24–25 (October 1999): 4029–4030, https://doi.org/10.1016/S1352-2310(99)00144-2.

[111] Krivoshto et al., "The Toxicity of Diesel Exhaust: Implications for Primary Care," 55.

B. PATHOLOGY OF DIESEL EXHAUST

Various studies have been performed to determine what effect diesel exhaust has on both workers and the general population. One of the most extensive early studies followed over 55,000 railroad workers exposed to diesel exhaust from locomotives for over 20 years. The results indicated that the rates of lung cancer in the subjects were linked to the diesel exhaust to which they were exposed.[112] That study examined high-risk workers who had direct exposure to diesel exhaust every day. In a similar study designed to determine what effects diesel exhaust had on workers, Garshick et al. did an analysis on 31,135 workers in the trucking industry. It was determined that workers exhibited an elevated risk of developing lung cancer resulting from a cumulative lifetime exposure.[113] After evaluating the mounting evidence, the EPA concluded that chronic exposure to diesel exhaust is likely to do damage to the lungs in a variety of ways and represents a probable lung cancer hazard.[114] The exposure that workers experience represents a concentrated quantity of what the general population encounters.

To determine what effect diesel PM had on those exposed to it, NIOSH initiated a study in 1995 on a cohort of underground miners.[115] Miners were chosen because they were exposed to high concentrations of diesel exhaust and a large enough cohort was available to give the study meaningful statistical significance. Not everybody was enthusiastic about the possible results of the study however. Much like the asbestos industry before, the diesel industry actively tried to suppress the study of the connection between diesel exhaust exposure and adverse health effects. In the case of this study, the Methane Awareness Resource Group (MARG) Diesel Coalition was formed and they

[112] Marc Schenker, "A Retrospective Cohort Study of Lung-Cancer and Diesel Exhaust Exposure in Railroad Workers," 823, Academia, accessed September 9, 2017, http://www.academia.edu/12497872/A_RETROSPECTIVE_COHORT_STUDY_OF_LUNG-CANCER_AND_DIESEL_EXHAUST_EXPOSURE_IN_RAILROAD_WORKERS.

[113] Eric Garshick et al., "Lung Cancer and Vehicle Exhaust in Trucking Industry Workers," *Environmental Health Perspectives* 116, no. 10 (October 2008): 1331, https://doi.org/10.1289/ehp.11293.

[114] "Health Assessment Document for Diesel Engine Exhaust," Federal Register, XIV, September 3, 2002, https://www.federalregister.gov/documents/2002/09/03/02-22368/health-assessment-document-for-diesel-engine-exhaust.

[115] Celeste Monforton, "Weight of the Evidence or Wait for the Evidence? Protecting Underground Miners from Diesel Particulate Matter," *American Journal of Public Health* 96, no. 2 (February 2006): 271, https://doi.org/10.2105/AJPH.2005.064410.

began obstructing the progress of the study before it even got started.[116] Through litigation, they were able to use the courts to delay the start of the study and gain control over the release of the results.[117] The MARG Coalition was able to impede the progress of the study while at the same time using the fact that it was still outstanding to delay regulatory efforts to improve the exposure rates. MARG lobbied Congress to delay any new regulatory rules until guidance could be given by the ongoing NIOSH and National Cancer Institute (NCI) study of exposed miners.[118] The tactics were so successful that the results of the study were not published until 2012, almost 20 years after the study was initiated. In the end, the study concluded, “The study findings provide further evidence that exposure to diesel exhaust increases risk of mortality from lung cancer and have important public health implications.”[119] While the results took almost two decades to be released, the report did go on to demonstrate that the harmful effects of diesel exhaust exposure represents not only an industrial hazard but also a danger to the general public as well.

The consequence of diesel exhaust goes beyond only affecting workers as it contributes extensively to the volume of particles in the atmosphere. It impacts the general population in the form of air pollution. As noted, diesel exhaust consists of hundreds of lethal chemicals and carcinogenic compounds, with soot contributing more than 50 percent of the overall PM found in air pollution.[120] Toxic compounds adhere to the surface of the particles and are transferred into the body through the circulatory system after they have been inhaled. Through experimental observation, it was determined that the PM from diesel exhaust plays a primary role in facilitating the

[116] Monforton, “Weight of the Evidence or Wait for the Evidence?”

[117] Ibid.

[118] Ibid.

[119] Michael D. Attfield et al., “The Diesel Exhaust in Miners Study: A Cohort Mortality Study with Emphasis on Lung Cancer,” *JNCI: Journal of the National Cancer Institute* 104, no. 11 (June 6, 2012): 869–83, https://doi.org/10.1093/jnci/djs035.

[120] Krivoshto et al., “The Toxicity of Diesel Exhaust: Implications for Primary Care,” 56.

damaging effects to the circulatory system that subjects displayed.[121] This mechanism of injury was highlighted in a study performed by Samet et al., who reviewed the mortality rates of 20 different cities. It was determined that the level of PM in the air had a direct association with cardiovascular and respiratory mortality.[122] Those findings indicate that the particles themselves contribute to the harmful consequence of air pollution.

The degree to which those toxic compounds and PM affect the body depends upon how they get distributed throughout the respiratory system. The particle dimensions play an integral role in that distribution as foreign bodies are filtered out naturally through the action of microscopic hairs called cilia and white blood cells that isolate them from the lung tissue.[123] The system is designed to capture and expel PM before it penetrates too far into the lungs. The PM that is inhaled will distribute at different locations throughout the respiratory system with the finer particles penetrating deeper and allowing for a greater diffusion of toxic compounds into the circulatory system. As Figure 3 shows, the PM that exists in the nanometer range are more easily inhaled and can deposit much deeper in the lungs to the alveoli where gas exchange occurs.[124] The smaller particles in the nanometer range then pose a greater threat than ones in the micrometer range.[125] The larger micrometer particles absorb less toxic compounds and will be more effectively managed by the respiratory system.

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[121] Ken Donaldson et al., "Combustion-Derived Nanoparticles: A Review of Their Toxicology Following Inhalation Exposure," *Particle and Fibre Toxicology* 2 (October 21, 2005): 2670, https://doi.org/10.1186/1743-8977-2-10.

[122] Jonathan M. Samet et al., "Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987–1994," *New England Journal of Medicine* 343, no. 24 (December 14, 2000): 1742, https://doi.org/10.1056/NEJM200012143432401.

[123] "Defense Mechanisms of the Respiratory System—Lung and Airway Disorders," Merck Manuals Consumer Version, accessed September 28, 2017, http://www.merckmanuals.com/home/lung-and-airway-disorders/biology-of-the-lungs-and-airways/defense-mechanisms-of-the-respiratory-system.

[124] Michael Guarnieri and John R. Balmes, "Outdoor Air Pollution and Asthma," *Lancet* 383, no. 9928 (May 3, 2014): 1581–92, https://doi.org/10.1016/S0140-6736(14)60617-6.

[125] David B. Kittelson, "Engines and Nanoparticles," *Journal of Aerosol Science* 29, no. 5–6 (June 1998): 575, https://doi.org/10.1016/S0021-8502(97)10037-4.

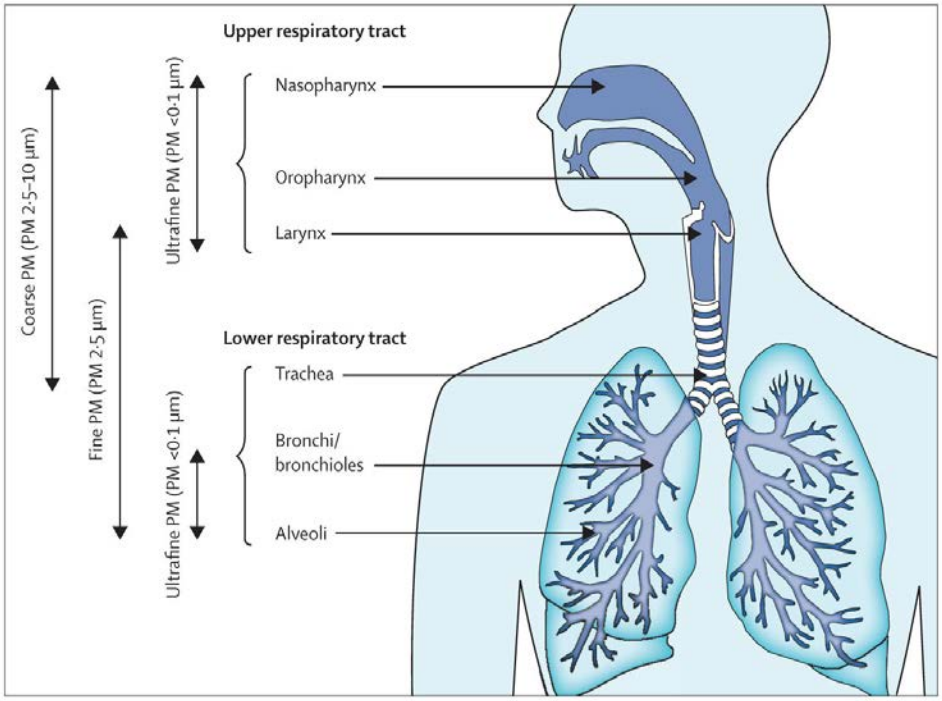

Figure 3. Particulate Matter Deposition Based on Particle Dimension[126]

This finding is especially concerning for diesel exhaust as the soot produced has a wide range of dimensions. The dimensions run from coarse (between 10–0.1 microns) to ultrafine (between 0.1–0.5 microns) down into nanoparticle range (less than .05 microns), with the majority of the particles falling into the nanoparticle range.[127] The diesel exhaust in that range is very effective at transporting toxic compounds into the circulatory system; a function of the inverse relationship between the size of the particles and how deep into the lungs they can reach. That size dependency has disturbing implications as new methods for reducing the weight of the PM in diesel exhaust ends up forming a greater number of finer particles.[128] The greater concentration of nanoparticles represents a larger surface area, which imparts more organic and inorganic compounds into the body.[129] While the dimensions of the individual particles decrease, a greater amount will

[126] Source: Guarnieri and Balmes, "Outdoor Air Pollution and Asthma," 24.

[127] Kittelson, "Engines and Nanoparticles," 577.

[128] "The Report on Diesel Exhaust," California Air Resources Board, accessed November 11, 2017, https://www.arb.ca.gov/toxics/dieseltac/de-fnds.htm.

[129] "Health Assessment Document for Diesel Engine Exhaust," 2–121.

be deposited deeper inside the lungs. That deeper deposition will go on to have a greater detrimental effect on the vascular system. In a study on the effects of diesel exhaust inhalation, Mills et al. revealed that a credible correlation exists between exposure to the products of air pollution and a heart attack.[130] As this process is better understood, efforts to minimize exposure will need to address particle dimensions, as well as particulate concentration.

C. DIESEL EXHAUST LITIGATION

The litigation for diesel exhaust exposure did not drive regulatory controls as it did in the case of asbestos. Regulators recognized the contribution that diesel exhaust was having on poor air quality and began controlling emissions as far back as 1970.[131] It was not until the 1990s that litigation began to demonstrate the liability of exposure diesel exhaust. In one of the first cases of injury caused by diesel exhaust, a railroad worker named Cox successfully sued CSX Transportation, Inc. for injury resulting from exposure to diesel exhaust.[132] The railroad conductor was awarded $3.5 million in damages after developing interstitial fibrosis due to substantial exposure to diesel exhaust from the locomotives.[133] The expert testimony also indicated that Mr. Cox had a 40 percent increase for developing lung cancer as a result of the exposure.[134] This case is significant because the court accepted the conclusions of expert testimony that his condition was the result of two years' worth of exposure.

In a similar case, a locomotive engineer, Phil Baker, died as a result of nasopharyngeal cancer allegedly caused by substantial exposure to exhaust from diesel

[130] Nicholas L. Mills et al., "Diesel Exhaust Inhalation Causes Vascular Dysfunction and Impaired Endogenous Fibrinolysis," *Circulation* 112, no. 25 (December 20, 2005): 3932, https://doi.org/10.1161/CIRCULATIONAHA.105.588962.

[131] Thomas W. Hesterberg et al., "Health Effects Research and Regulation of Diesel Exhaust: An Historical Overview Focused on Lung Cancer Risk," *Inhalation Toxicology* 24, no. s1 (June 2012): 3, https://doi.org/10.3109/08958378.2012.691913.

[132] Shaw V. Dow Brands, Inc (United States Court of Appeals for the Seventh Circuit, 1992), 21.

[133] Ibid.

[134] "—FELA—Exposure to Diesel Train Exhaust Emissions—Interstitial Fibrosis—Increased Chance of Lung Cancer," Zarin's Jury Verdict Review & Analysis, accessed November 13, 2017, http://www.jvra.com/verdict_trak/article.aspx?id=27314.

locomotives.[135] His widow brought a lawsuit against the Norfolk Southern Railway Company in 1999 and was awarded over $5 million in compensation.[136] Again, the court accepted the testimony of expert witnesses who determined that the diesel exhaust appeared to be the cause of the cancer. Dr. Epstein, the expert witness for Mr. Baker's estate, testified that diesel exhaust "contains soot particles which absorb the exhaust's carcinogenic gases and then, when inhaled, accumulates these concentrated carcinogens in the nasopharynx."[137] This accumulation represents the same mechanism of injury that nanoparticles in diesel exhaust pose for the deeper regions of the respiratory system. These cases demonstrate how much damage a hazard, such as diesel exhaust, can pose to workers even as the scientific evidence is being explored.

D. REGULATORY CONTROLS

Regulatory actions taken against diesel exhaust pollution in America began in earnest with the Clean Air Act of 1970. In it, the EPA limited motor vehicle emissions and established air quality standards nationwide.[138] This forced diesel engine manufacturers to create new ways of scrubbing the exhaust. Improved fuel injection equipment, sensors, and exhaust gas recirculation helped meet those regulatory standards.[139] As time went by, more stringent controls required ever more reduced emissions. The regulation initially focused on reducing the various gases produced, leaving PM unregulated for the most part.[140] The mechanism of how the particles absorb toxic compounds onto the surface remained largely unacknowledged. It was not until 1987 that the EPA began setting standards for the PM emitted from vehicles.[141] Those standards were met by providing cleaner burning fuel, installing engine exhaust filters,

[135] "FindLaw's Court of Appeals of Georgia Case and Opinions," Findlaw, accessed November 13, 2017, http://caselaw.findlaw.com/ga-court-of-appeals/1127350.html.

[136] Ibid.

[137] Ibid.

[138] "Clean Air Act Requirements and History," Environmental Protection Agency, May 27, 2015, https://www.epa.gov/clean-air-act-overview/clean-air-act-requirements-and-history.

[139] Timothy V. Johnson, *Diesel Emission Control: 2001 in Review*, 2002-01-0285 (Warrendale, PA: SAE Technical Paper, 2002), 5, http://papers.sae.org/2002-01-0285/.

[140] Hesterberg et al., "Health Effects Research and Regulation of Diesel Exhaust," 3.

[141] Ibid., 4.

and catalytic converters on newer manufactured vehicles. As researchers began to recognize the danger that the smaller particles posed, the air quality standards began to concentrate on ever-smaller particles.[142] To understand what possible injury the PM in the nano-scale might cause, science has now begun to take a closer look at those particles.

As concern for the possible health effects of CNT became an issue, researchers began to re-examine diesel exhaust to determine whether a connection existed. It was established that CNT can be combustion-generated and are found in exhaust from diesel fuel, methane, propane, and natural gas.[143] Since the particles in diesel exhaust are such a major component of the overall PM in air pollution, the next step was to determine what effect CNT from diesel exhaust had on those exposed to it. It was revealed that ambient levels of PM influenced allergic inflammation with some evidence indicating that it contributed to new cases of asthma.[144] A closer look at people living in inner cities was taken to investigate the possible link between exposure to combustion-based CNT, from diesel exhaust and lung sensitivity. One such study performed in Paris determined that CNT were present in the lungs of 64 children who suffered from asthma.[145] This study was the first time that the cells lining the lungs were examined for the presence of CNT. The study also found the same CNT on the exhaust pipes of cars and in random samples of dust from around the city.[146] The findings suggest that the PM from diesel exhaust is effective at transmitting CNT into the lungs. This finding is alarming for members of the fire service, as their exposure to diesel exhaust has been so poorly managed over the years.

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[142] Hesterberg et al., "Health Effects Research and Regulation of Diesel Exhaust," 4.

[143] Barna, Judson, and Thomassen, "Carbon Nanotubes and Chronic Granulomatous Disease," 508.

[144] Guarnieri and Balmes, "Outdoor Air Pollution and Asthma," 5.

[145] Kolosnjaj-Tabi et al., "Anthropogenic Carbon Nanotubes Found in the Airways of Parisian Children," 1700.

[146] Ibid.

E. IMPACT ON THE FIRE SERVICE

Most major fire departments in the United States began to convert their apparatus to diesel power in 1970s. During this time, little consideration was given to the effects that diesel exhaust exposure would have on the firefighters working and essentially living in the firehouse. Houses designed for steam apparatus and even horse drawn apparatus had diesel-driven vehicles installed without any accompanying air handling measures. By 1988, after the health effects were more thoroughly documented, NIOSH acknowledged that diesel exhaust should be regarded as "a potential occupational carcinogen."[147] It took approximately 20 years from the time when diesel engines began to be utilized extensively in the fire service for NIOSH to acknowledge that an association could exist between exposure to diesel exhaust and cancer. That connection is significant for the fire service in light of a health assessment that the EPA published on diesel engine exhaust in 2002. In it, the EPA estimated that firefighters have the second highest occupational exposure range to diesel particulate matter only behind miners.[148] That particulate matter infiltrates all areas of the firehouse, and as noted earlier, it carries lethal toxins with it. While advances in air handling systems and firehouse construction have been made, 50 years later, a federal regulation controlling the levels of diesel exhaust inside a firehouse still has not been established.

While the threat of diesel exhaust exposure is still being researched, measures are being taken to mitigate the hazard. Much like the threat of asbestos, diesel exhaust exposure is being addressed through the regulation of future products. New engines are designed to run cleaner through the use of exhaust filters, pressure and temperature variations, and emissions control additives. The results are that the EPA expects exhaust particulate from vehicle engines to decrease as much as 90 percent due to cleaner engines conforming to current regulations.[149] While those projections are promising, many current diesel engines continue to contribute to air pollution. Like the asbestos crisis that

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[147] Donald J. Millar, *Carcinogenic Effects of Exposure to Diesel Exhaust*, Publication Number 88-116 (Washington, DC: National Institute for Occupational Safety and Health (NOISH), 1988), https://www.cdc.gov/niosh/docs/88-116/.

[148] "Health Assessment Document for Diesel Engine Exhaust," 2–125.

[149] Ibid., XV.

continues to have lethal consequences globally, diesel exhaust has had lasting effects on the health of the millions exposed to it.

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IV. REGULATORY CONTROLS FOR NANOTECHNOLOGY

Earlier chapters have indicated that inadequate regulatory oversight in the past has left the fire service exposed to a variety of emerging threats. The examples of asbestos and diesel exhaust demonstrate that safety is often a secondary consideration in the face of progress. Nanotechnology represents the latest cutting-edge technology that is going through the regulatory process. As this technology becomes utilized more extensively and better understood, the government is cautiously regulating usage in an attempt to balance the promise of economic benefits against potential hazards. The technological advancement of the material, however, is currently outpacing the discussion on how to regulate the environmental and health risks best.[150] That regulation has a profound impact on individuals who interact with the many products that incorporate nanotechnology. This chapter points out some of the issues that influence regulation of nanotechnology and CNT in particular, and what implications those regulations have for the fire service. The conflict between the economic and safety interests for nanotechnology is considered to understand what forces influence regulatory decisions. Those conflicting interests are following a similar pattern to the earlier examples of asbestos and diesel fuel with the added burden of international trade shaping regulatory decisions. Deficient international trade agreements and the resulting competition are examined to appreciate why effective regulatory cooperation remains elusive. By understanding the regulatory process and the interests that act upon it, the fire service is able to take proactive measures to provide safeguards for the members.

A. THE PROMISE OF NANOTECHNOLOGY

Nanotechnology has the potential to improve currently manufactured products, as well as create new ones throughout a wide range of industries. The International Organization for Standardization defines nanomaterial as “material with any external dimensions in the Nano scale or having internal structure or surface structure in the Nano

[150] Robert Falkner and Nico Jaspers, “Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap,” *Global Environmental Politics* 12, no. 1 (January 13, 2012): 30, https://doi.org/10.1162/GLEP_a_00096.

scale."[151] When that nanomaterial is manipulated into CNT, for example, carbon-based composites are created that are hollow on the inside while maintaining an extremely stable structure. The carbon is manipulated on the atomic scale to align the atoms into a specific tube-shaped arrangement.[152] The lightweight hollow structure of nanotubes and the increased surface area create unique properties, such as enhanced thermal and electrical conductivity, as well as a high strength to weight ratio.[153] The ability to manipulate the structures on the atomic level has led to the construction of stronger and lighter materials. This diversity is what makes CNT such a valuable economic resource.

Governments grapple with a variety of issues as they endeavor to regulate new products that incorporate nanotechnology. Issues as diverse as the definition of what constitutes nanotechnology, conflicting opinions on health consequences, and economic and trade concerns all contribute to shaping regulation and policy.[154] Governing bodies, in an attempt to address all concerns, often take an incremental approach to governance. Small, manageable limitations are put into place with more restrictive measures enacted as needed in the future. That incremental approach balances the economic and safety interests, allowing the technology to continue to develop while science gains a clearer understanding of the health implications. The concern with that approach is that regulators have been surprised by how quickly some products containing nanotechnology have moved from research to production.[155] In the past, that approach has left many to deal with the negative consequences of exposure. In the case of asbestos, guidance began with better industrial hygiene for the workers handling the material. It eventually led to a total ban of the material in many countries and heavily restricted use in others. For the regulation of diesel exhaust, the government set even more stringent emission standards

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[151] "Commission Recommendation of 18 October 2011 on the Definition of Nanomaterial," European Commission, accessed June 13, 2017, https://www.researchgate.net/publication/285151241_Commission_Recommendation_of_18_October_2011_on_the_definition_of_nanomaterial.

[152] "CNT Technology Overview."

[153] Donaldson et al., *The Toxicology of Carbon Nanotubes*, 1.

[154] Kirsten Rodine-Hardy and Anne Clunan, *Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology* (Monterey, CA: Center on Contemporary Conflict, 2014), http://calhoun.nps.edu/handle/10945/43101.

[155] Falkner and Jaspers, "Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap," 10.

on the engines that produced the majority of the byproducts. Regulation was also tailored over the years to fit the threat as science clarified which gases and what particulate matter posed the greatest threat. As the pattern of asbestos and diesel exhaust exposure demonstrate, that incremental approach to regulation can leave the fire service vulnerable to the hazards of exposure.

Local jurisdictions look to federal policy for guidance on managing complex problems that pose a health threat. By examining how nanotechnology is currently regulated, the fire service can make educated decisions on whether enough is being done at the federal level and what further measures should be taken. Since this health threat represents a potential issue for the membership, it is important to recognize fully how serious the threat is and to take the most prudent course of action. By understanding current guidance on recommended exposure limits and various levels of personal protective equipment (PPE), the fire service will gain a sense of awareness about the danger that exists. Proactive measures can then be taken to both raise awareness of the issues, as well as provide guidance on how to mitigate exposure. Measures, such as providing exposure data to help guide future regulation and enacting stringent decontamination methods will allow the fire service to take an active role in the safety of the members. To understand the significance of nanotechnology legislation, the fire service must first appreciate the impact of the technology.

B. THE INFLUENCE OF ECONOMIC INTERESTS

The ability to produce nano-structures, such as CNT on an industrial scale has the potential to revolutionize manufacturing. As noted in Chapter I, CNT have improved numerous products, such as ceramics, sunscreens, biosensors, solar cells, military technology, textiles, and surface finishes.[156] The versatility of the material has profound implications for industrialized countries, as well as emerging nations. It has been speculated that nanotechnology may potentially transform warfare, society, and even the

[156] Scientific Committee on Emerging and Newly Identified Health Risks, *The Appropriateness of Existing Methodologies to Assess the Potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies*, 5.

current geopolitical hierarchy.[157] Such substantial economic consequences have a significant influence on the development of regulation. As Senator George Allen, Virginia, stated while discussing the National Nanotechnology Program, "I am increasingly convinced that U.S. economic competitiveness in the global marketplace depends on success in developing a vibrant and innovative nanotechnology community."[158] The competition generated between the overwhelming economic potential and the health implications hinders policy making. In fact, the economic potential has so dominated the debate that Anne Clunan and Kirsten Rodine-Hardy from the Center on Contemporary Conflict found in a study in 2014, "Despite the significant military potential and possible toxicity of nanoparticles, there has been very little effort made to develop national or multilateral regulations that specifically regulate nanotechnologies."[159] The fear of malicious use, or the deleterious effects of exposure to nanotechnology, has been overshadowed by the threat of losing a competitive edge in this groundbreaking field.

Maintaining a competitive edge on the global economic stage is an essential priority for the United States. Significant global investment has taken place in nanotechnology with a current estimate of nearly $250 billion by 2015 through private and public funding.[160] While the expectations of economic returns are substantial, the health threats posed must also be considered as the technology is developed. The threat from accidental exposure is a discernable one, but the potential for nefarious exposure is not as obvious. As Margaret Kosal points out in her book, *Nanotechnology for Chemical and Biological Defense*, "large-scale commercial production of nanoparticles is expected to increase rapidly over the next fifteen years. Should results confirm the toxicity of such nanoparticles, future ease of access and low cost may make them attractive as

[157] Rodine-Hardy and Clunan, *Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology*, ii.

[158] "The Economic Promise of Nanotechnology," Issues in Science and Technology, accessed June 11, 2017, http://issues.org/21-4/allen/.

[159] Rodine-Hardy and Clunan, *Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology*, 17.

[160] "The 2011 Report on Global Nanotechnology Funding and Impact," Cientifica Research, July 13, 2011, http://www.cientifica.com/the-2011-report-on-global-nanotechnology-funding-and-impact/.

‘conventional’ weapons of mass destruction or effect.”[161] The threat of nanotechnology as a cheap and abundant weapon is a consequence of ever reducing production costs and the physiological effects of CNT. That threat cannot be managed locally given the amount of international trade that occurs in nanotechnology.

Some of the major issues shaping regulatory policy are economic and trade restrictions, military application, and exposure repercussions. As Anne Clunan and Kirsten Rodin-Hardy found in their 2014 study, “The policy challenge entails encouraging the proliferation of Nano science and nanotechnology and cultivating safe development and commercialization of nanotech-based products, while regulating in order to prevent malfeasant uses and mitigate against harmful effects of this technology.”[162] Those competing concerns create a complexity with which policy makers wrestle. The economic potential of nanotechnology has a major impact on international trade agreements, as well as regulatory policy within individual countries. As noted, local jurisdictions often look to federal regulatory policy for guidance on how to address emerging threats. If that federal regulation is lacking then those local jurisdictions need to be aware of the consequences.

C. THE UNITED STATES AND THE EUROPEAN UNION

The principal economic concern that is influencing the governing of this emerging technology is the trade benefits associated with manufacturing. To understand better how it has affected regulatory policy, it is useful to compare how major trade partners currently govern nanotechnology. The individual trade interests of the United States and the European Union are examined as they represent the main global trading partners. In fact, the trade relationship between the United States and the European Union (EU) is the largest mutual trade partnership in the world.[163] That partnership demonstrates how the

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[161] Margaret Kosal, *Nanotechnology for Chemical and Biological Defense* (New York: Springer, 2009), 95, http://www.springer.com/us/book/9781441900616.

[162] Rodine-Hardy and Clunan, *Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology*, 17.

[163] “USA-EU—International Trade and Investment Statistics—Statistics Explained,”euroststat, accessed October 5, 2017, http://ec.europa.eu/eurostat/statistics-explained/index.php/USA-EU_-_international_trade_and_investment_statistics.

economic potential of nanotechnology can guide regulatory policy. The EU was chosen for comparison because it represents a jurisdiction with similar competing concerns to those of the United States.

The EU is a confederation of 28 countries with common economic interests. Laws are created to allow the citizens of EU countries to move and trade openly across their internal borders so that smaller member nations can manage economics and trade more effectively on the world stage. Each country is also obligated to accept the policy decisions made by the governing body. The EU regulates through the European Commission with a goal to deliver "maximum benefits to citizens, businesses and workers while avoiding all unnecessary regulatory burdens."[164] All policy therefore is guided by the needs of the people in conjunction with the economic needs of the entire union. That statement expresses their desire to avoid overregulation and allow all members to benefit economically. A balance must be found, however, between the benefits that new nanomaterials offer and the regulation that must be put in place to ensure safety.

The regulatory debate over how to govern products containing nanotechnology starts with the very definition of what it is. Such an elemental concept characterizes the type of hurdles faced in the development of good guidance. The definition presents an obstacle because of the instances of incidentally occurring nanomaterial as opposed to engineered ones. In cases like diesel exhaust, nanomaterial, such as CNT, are created as a byproduct of burning diesel fuel. The use of the original product is not designed to incorporate the unique features of the nanomaterial. If guidance is applied to a definition that is too broad, products not intended to employ nanotechnology may be overregulated. On the other hand, if the definition is too narrow, the regulation may not be applied to products that do feature nanotechnology and thereby become ineffective. New products could be created to avoid the regulation designed to oversee their production.

Both governing bodies have addressed the issue with a very different approach. The EU has taken a conservative stand and applied size as the determining criteria for

[164] "Better Regulation in the Commission," European Commission, accessed June 17, 2017, http://ec.europa.eu/smart-regulation/guidelines/ug_chap1_en.htm.

regulation, regardless of how the material was created. It has established that nanomaterial shall be defined as “a natural, incidental or manufactured material containing particles, in an unb–ound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1nm–100nm.”[165] The intent is to manage potentially harmful nanotechnology even if it is naturally or incidentally occurring. It has concluded that if nanomaterial is produced as a byproduct, it should still be regulated. The United States, however, applies a definition based on not only size, but one that also accounts for the unique properties that engineered nanotechnology specifically exploits. “Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100nm, the size-scale between individual atoms and bulk materials, where unique phenomena enable novel applications.”[166] The use of this definition excludes naturally occurring or incidental nanomaterial to avoid regulating products not specifically engineered for those properties. The intent is to avoid subjecting manufactured goods that have byproducts in the nanoscale range to the same level of regulation.

Despite the variance in definition and the lack of a definitive scientific consensus with regard to the health implications, measures have been taken to establish nanotechnology regulation. The EU created a new chemical legislation called Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) to adopt more specific rules and more extensive labeling for food and cosmetics that incorporate nanotechnology.[167] Since the majority of nanomaterial on the market is in chemical form, the REACH program is the main regulator of nanomaterial in the EU.[168] The United States, conversely, chose to coordinate nanotechnology regulation by channeling federal

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[165] “Definition of a Nanomaterial,” European Commission, accessed June 11, 2017, http://ec.europa.eu/environment/chemicals/nanotech/faq/definition_en.htm.

[166] John F. Sargent Jr., *The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues*, CRS Report No. RL34401 (Washington, DC: Congressional Research Service, 2014), 1, https://fas.org/sgp/crs/misc/RL34401.pdf.

[167] Falkner and Jaspers, “Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap,” 16.

[168] Ibid.

funding of nanotechnology through the National Nanotechnology Initiative (NNI).[169] The issue is that there are different agencies governing the numerous products containing nanotechnology. The EPA governs the risks associated with chemicals and pesticides while the Food and Drug Administration (FDA) controls the drugs, medical devices, food, and cosmetics.[170] OSHA manages workplace safety issues while the Consumer Product Safety Commission deals with consumer products.[171] This division represents a de-centralized approach to regulatory policy that has emerged. By consolidating control of funding through the NNI, the government is attempting to control research, development, and policy of all the various agencies.[172] Where the EU chose to regulate through legislation, the United States decided to use the control of funding to oversee policy. Both governing bodies, however, rely on self-reporting by industry to track and oversee creation of new products containing nanotechnology.

In the face of uncertainty and debate, the EU has initiated a more cautionary approach to nanotechnology regulation than the United States. Scientists are continuing to study the physiological effects of nanotechnology with an ever-increasing amount of funding provided annually to establish suitable guidance. Given the unique properties of nanotechnology, the EU has created bodies to standardize definitions and precautions and it has regulated nanotechnology as it does new chemicals.[173] The REACH program has recommended that legislation be passed to provide training and health surveillance for workers exposed to nanomaterials.[174] It has also mandated that suppliers or importers of dangerous chemical substances, under which nanotechnology is currently being regulated, must provide safety data sheets (SDS) for product information so that specific

[169] Falkner and Jaspers, "Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap," 13.

[170] Ibid.

[171] Ibid.

[172] Ibid.

[173] Aida Maria Ponce Del Castillo, *The EU Approach to Regulating Nanotechnology* (Brussels, Belgium: European Trade Union Institute, 2010), 19, ec.europa.eu/DocsRoom/documents/5716/attachments/1/translations/en/.../native.

[174] Ibid., 15.

risk management controls can be created.[175] These measures can provide guidance for the fire service and for U.S. governance. The fire service could lobby to have stronger regulation to provide better labeling requirements for products manufactured using nanomaterials. The oversight of nanomaterials in the United States could benefit from a more coordinated structure.

The various regulatory agencies that the United States has tasked with overseeing nanotechnology controls are managing new products within the framework of the current laws and regulations that each agency possesses. The EPA regulates nanomaterial based on the TSCA, a law enacted in 1976 designed to regulate new or current chemical substances.[176] It gives the EPA the authority to oversee testing, reporting, record keeping, and regulation of chemicals. This 40-year-old law, however, was never intended to manage the unique features of nanomaterials. The EPA has acknowledged that a need exists for greater research on the toxicology of nanomaterials. The introduction of the Nanoscale Materials Stewardship Program (NMSP) attempted to promote greater collaboration between private industry and other agencies.[177] The NMSP encouraged industry to self-report any relevant safety information on nanomaterials being created. The lack of cooperation in the self-reporting initiative, however, prompted the EPA to propose mandatory reporting rules in 2011.[178] Even with mandatory reporting legislation, the EPA concedes that knowledge gaps exist that present significant obstacles to managing nanomaterials. In its self-assessment in 2011, the EPA determined that "If EPA does not improve its internal coordination and develop a clear and consistent stakeholder communication process, the Agency will not be able to assure that it is effectively managing nanomaterial risks."[179] While the Agency is dealing with communication

[175] Del Castillo, *The EU Approach to Regulating Nanotechnology*, 20.

[176] "Summary of the Toxic Substances Control Act," Environmental Protection Agency, February 22, 2013, https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

[177] Falkner and Jaspers, "Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap," 15.

[178] Office of Inspector General, *EPA Needs to Manage Nanomaterial Risks More Effectively*, Report No. 12-P-0162 (Washington, DC: U.S. Environmental Protection Agency, 2011), https://www.epa.gov/office-inspector-general/report-epa-needs-manage-nanomaterial-risks-more-effectively.

[179] Ibid., 11.

issues and the limitations of existing laws, nanotechnology is emerging onto the marketplace at an ever more rapid pace. This quick rate will result in deficient regulation and labeling of nanomaterial in the future.

The FDA has attempted to give guidance to manufacturers, suppliers, importers, and other stakeholders to address the health and safety implications for products that contain engineered nanotechnology.[180] This guidance gives industry a gauge to determine if a product needs further attention to address any unique consequences of incorporating nanotechnology. This guidance relies on industry to self-evaluate its product and contact the FDA if it feels that further evaluation is necessary. The guidance, however, represents a recommendation based on the FDA's current opinion on the topic and is intended to evolve as scientific insight continues to expand.[181] While the FDA is regulating individual products utilizing existing legal standards, it is still relying on self-reporting based on issued guidelines. The problem is that the EPA has already acknowledged that industry self-reporting is ineffective; yet another warning to the fire service that it must not count solely on regulatory controls. The next step is to look at how nanotechnology is regulated for the workers who handle the material.

OSHA is responsible for regulating the safety and health conditions for workers. It is mandated to ensure a safe working environment for all workers by providing research, information, education, and training through the OSHA Act of 1970.[182] It has issued a fact sheet for working safely with nanotechnology. In it, it highlights the potential hazards of handling nanomaterial and outline preventative procedures to control workplace exposure.[183] The fact sheet outlines information and training that should be provided to workers who will be exposed to nanomaterial. As with the FDA's guidance,

[180] "Considering Whether an FDA-Regulated Product Involves the Application of Nanotechnology," U.S. Food & Drug Administration, June 2014, https://www.fda.gov/RegulatoryInformation/Guidances/ucm257698.htm.

[181] Ibid.

[182] "OSH Act of 1970," Occupational Safety and Health Administration, accessed October 24, 2017, https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=OSHACT&p_toc_level=0&p_keyvalue=.

[183] Lynn L. Bergeson, "OSHA Publishes Fact Sheet on Working Safely with Nanomaterials," *Nano and Other Emerging Chemical Technologies* (blog), February 5, 2013, http://nanotech.lawbc.com/2013/02/osha-publishes-fact-sheet-on-working-safely-with-nanomaterials/.

it represents a recommendation-based document that acknowledges the rapid advance of nanotechnology and the ongoing effort to develop appropriate worker exposure limits. OSHA looks to NIOSH to give guidance on the health and safety implications of any occupational hazard. As such, NIOSH has become the lead federal agency researching the consequences of nanotechnology.[184] While NIOSH has established exposure limits for CNT and titanium dioxide, exposure limits for other nanomaterial does not yet exist.[185] As the research continues and occupational guidance is developed for workers handling nanotechnology, little consideration is given for exposure to the fire service. As with asbestos and diesel exhaust in the past, the effects will be studied as the consequences of exposure present themselves. While OSHA continues to strive to protect workers using current hazard control measures and best practices, the fire service must determine what its own level of protection will be for nanotechnology to mitigate the effects of exposure.

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[184] "Nanotechnology at NIOSH," Centers for Disease Control and Prevention, accessed November 2, 2017, https://www.cdc.gov/niosh/topics/nanotech/nanotechnology-research-center.html.

[185] Bergeson, "OSHA Publishes Fact Sheet on Working Safely with Nanomaterials."

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V. CONCLUSION

This thesis has demonstrated that the threat of nanotechnology is not yet fully understood and that the fire service cannot rely on federal regulation alone, to provide adequate guidance for the safety of the members. The competing interests of economics and safety combined with the current regulatory hurdles results in insufficient oversight for the level of risk that the fire service will encounter. As the examples of asbestos and diesel exhaust exposure have demonstrated, in the absence of clear scientific data, industry will forge forward despite the health implications. The fire service must therefore take the initiative and act in a manner that will forestall their vulnerability.

A. RECOMMENDATIONS

The following recommendations should be developed and initiated:

- Initiate a study to determine the most effective decontamination procedures to employ during operations involving nanomaterial. The most logical solution is to follow current asbestos exposure protocols. As mentioned earlier, experimental results indicate that CNT can cause a physiological response similar to that of asbestos exposure. By following asbestos protocols, the fire service can take an incremental step towards safety until scientific results clarify the exposure hazard.

- Develop effective monitoring and education controls to understand the health effects of exposure. As the consequences of exposure to nanomaterials in a fire become more thoroughly understood, the fire service will be in a position to recognize better what the causation is for health issues that may manifest. NIOSH has proposed a REL for CNT not to exceed 1.0 micrograms per cubic meter as an 8-hour time-weighted average for workers handling nanotechnology.[186] Understanding how

[186] Department of Health and Human Services, *Occupational Exposure to Carbon Nanotubes and Nanofibers: Current Intelligence Bulletin 65*, 5.

NIOSH determines such a REL will give the fire service a greater awareness of the threat.

- Require SDS be available to alert the fire service of the hazard of accidental release of CNT. OSHA requires manufacturers and transporters to produce SDS for all hazardous materials.[187] The sheets represent the principal source of information regarding the hazards of chemicals and can be used to make risk or reward decisions during an emergency response.[188] The fire service should mandate that those sheets be attached to products that incorporate CNT into their matrix. Used in conjunction with mandatory warning labels and premarket safety evaluations, those sheets would be an important asset for an on scene threat assessment.

B. IMPLEMENTATION

To implement the aforementioned recommendations, the fire service must first recognize the threat that nanotechnology poses. The competing interests that convolute effective regulation must also be understood to avoid overreliance. While it is understandably difficult to initiate protective measures given the confusing federal guidance, the potential health threat to the fire service is significant. As such, a working group should be set up consisting of members trained in proper decontamination procedures for hazardous material exposure. It must include medical professionals who can advise on the most likely exposure vectors associated with nanotechnology. The medical staff should also develop a reporting system to make the results of medical screening available to members.

The fire service medical staff should devise medical monitoring and education controls that can be incorporated into current annual medical monitoring programs. These medical protocols should include screening for CNT to understand how exposure is

[187] "Hazard Communication Standard: Safety Data Sheets—OSHA 3514," Occupational Safety and Health Administration, accessed October 26, 2017, https://www.osha.gov/Publications/OSHA3514.html.

[188] Adrienne Eastlake et al., "A Critical Evaluation of Material Safety Data Sheets (MSDSs) for Engineered Nanomaterials," *Journal of Chemical Health and Safety* 19, no. 5 (September–October 2012): 1–8, https://doi.org/10.1016/j.jchas.2012.02.002.

affecting members over time. That data can then be shared with other medical professionals so that a comprehensive risk assessment can be performed. They should participate in the newly formed Emerging Technologies Interagency Policy Coordination Committee (ETIPC) to provide guidance for the risk or benefit-based oversight mechanisms being developed.[189] In this way, the fire service can influence future safety measures as they are being developed.

Finally, the fire department must join with other concerned organizations, such as trade unions, environmental advocates, and regulatory bodies, to standardize SDS so that they are provided with materials that incorporate nanotechnology. The sheets would alert first responders to the hazards associated with the particular materials in use at a location. In a random sample of SDS, formally known as material safety data sheets (MSDS), OSHA determined that the sheets "provide insufficient data for communicating the potential hazards of engineered nanomaterials."[190] The fire service should convey what necessary information is needed on each SDS so that it will be aware of the hazards and be able to determine what controls are necessary.

In light of this emerging hazard, the fire department has a moral obligation to take preemptive measures to ensure the continued health and well-being of the members. The manner in which the fire department handles the threat of nanotechnology may set the benchmark for addressing other emerging threats. By prioritizing health and safety while this technology is being developed, the fire department may avoid the mistakes made in the past with exposure to asbestos and diesel exhaust while demonstrating how to best manage potential hazards in the future.

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[189] Heather Evans, "Emerging Technologies IPC Has Inaugural Meeting," *White House* (blog), May 15, 2010, https://obamawhitehouse.archives.gov/blog/2010/05/15/emerging-technologies-ipc-has-inaugural-meeting.

[190] Eastlake et al., "A Critical Evaluation of Material Safety Data Sheets (MSDSs) for Engineered Nanomaterials."

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