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Fire as a weapon: high-rise structures

Sheppard, Adrian Bernard

Monterey, California: Naval Postgraduate School

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THESIS

FIRE AS A WEAPON: HIGH-RISE STRUCTURES

by

Adrian Bernard Sheppard

December 2017

Thesis Advisor: Carolyn Halladay
Second Reader: Lauren Wollman

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13. ABSTRACT (maximum 200 words)

This thesis identifies an emerging problem space, high-rise pyro-terrorism. Although modern urban environments are vulnerable to sophisticated arson, and terrorists and lone-wolf attackers have exploited that vulnerability, neither practitioners nor the academic community have addressed the unique threat posed by arson. This thesis fills that gap by showing, first, that a good reason exists to believe that terrorists will use arson against high-profile urban targets in the future; second, that existing regulatory strategies may be sufficient to guard against accidental fires and opportunistic arson, but have weaknesses that sophisticated attackers can identify and exploit; and third, that the approach to urban firefighting must be modified to protect first responders, improve life safety in cases of pyro-terrorism, and facilitate effective collaboration with counter-terrorism forces. This thesis is valuable for an academic audience because it identifies the most pressing gaps in the literature on pyro-terrorism and explains their significance. It is also valuable to practitioners because it highlights vulnerabilities that can be addressed immediately, in a proactive rather than a reactive way.

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FIRE AS A WEAPON: HIGH-RISE STRUCTURES

Adrian Barnard Sheppard
Fire Chief, City of Richmond, California
B.S., Embry-Riddle Aeronautical University, 1989
M.S., Grand Canyon University, 2014

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Approved by: Carolyn Halladay
Thesis Advisor

Lauren Wollman
Second Reader

Erik Dahl
Associate Chair for Instruction
Department of National Security Affairs

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ABSTRACT

This thesis identifies an emerging problem space, high-rise pyro-terrorism. Although modern urban environments are vulnerable to sophisticated arson, and terrorists and lone-wolf attackers have exploited that vulnerability, neither practitioners nor the academic community have addressed the unique threat posed by arson. This thesis fills that gap by showing, first, that a good reason exists to believe that terrorists will use arson against high-profile urban targets in the future; second, that existing regulatory strategies may be sufficient to guard against accidental fires and opportunistic arson, but have weaknesses that sophisticated attackers can identify and exploit; and third, that the approach to urban firefighting must be modified to protect first responders, improve life safety in cases of pyro-terrorism, and facilitate effective collaboration with counter-terrorism forces. This thesis is valuable for an academic audience because it identifies the most pressing gaps in the literature on pyro-terrorism and explains their significance. It is also valuable to practitioners because it highlights vulnerabilities that can be addressed immediately, in a proactive rather than a reactive way.

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LIST OF ACRONYMS AND ABBREVIATIONS

ALF	Animal Liberation Front
ELF	Earth Liberation Front
HVAC	heating, ventilation, and air conditioning
IED	improvised explosive device
NIMS	National Incident Management System
RSET/ASET	required safe egress time to available safe egress time

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EXECUTIVE SUMMARY

Pyro-terrorism, the purposeful ignition of fire with the intention of causing harm, can make firefighting so complex that it eventually stretches the resources of a firefighting department to the limit. The need to preempt terrorist attacks on buildings has forced fire departments to create counter-terrorism units on an unprecedented scale. This thesis seeks to answer two questions. First, which approaches should fire departments use for mitigating, preparing for, and responding to pyro-terrorism occurrences within building structures? Second, how should fire departments improve their strategies for managing pyro-terrorism events? To get answers to these questions, the thesis draws on the relevant literature on the following conceptual themes: how arson is effective as a tool for random destruction, how to mitigate fire outbreaks in buildings, and the potential weaknesses of the methods used for such mitigation.

The findings suggest that a major concern in the mitigation of the threat that pyro-terrorism poses is how to allocate resources and understand the most significant ways in which this threat manifests itself. The existing theoretical frameworks do not address the needs of counter-terrorism, but it is possible to adapt them for use in counter-terrorism contexts. Also, from the findings, it is clear that two principles should guide the developers of building codes; building codes are a crucial tool for risk mitigation. First, the codes must have narrow tailoring meant to offer protection to buildings facing the highest risk, but they should do so without imposing undue needs on other developments. Second, building codes should be suitable for not only managing a building's risk exposure but also creating standard features of structure that should remain the same for all buildings.

Tactical responses, too, are a fundamental pillar in addressing the problems facing the counter-terrorism units of fire departments; these departments need to explore the value of high-rise elevators for immediate response operations. However, the literature does not address how counter-terrorism units can manage elevators efficiently when evacuation needs to be done on short notice. In addition, the increasing height of high-rise buildings necessitates making use of elevators for both evacuation and firefighter

transportation, which creates a vulnerability to sabotage. The robust safety mechanisms for elevators do not seem suited to the challenges facing firefighters in counter-terrorism operations. Counter-terrorism units of fire departments also have to contend with the reluctance of other security agencies to share intelligence with departments that do not play a role in homeland security. The reluctance of other agencies to share information with fire departments stems from the potential for that information to leak and undermine long-term security strategies. An urgent need exists for a mechanism that allows fire departments to obtain specific information about potential terrorist attacks long before these attacks occur without undermining the long-term interests of other security agencies.

This thesis recommends that fire departments develop a framework for mapping out the risk of pyro-terrorists targeting a building; such a framework should allow rigorous cost-benefit analyses and coordination among the various teams managing risks. Also, fire departments must cooperate with architects and engineers to develop a framework of building codes so that regulators have a mechanism for mapping out potential pyro-terrorism risks when they are assessing construction projects. The thesis also recommends that industry professionals come up with ways of adapting fire chronologies to evaluate the possibilities that a fire incident resulted from pyro terrorism. Adapting fire chronologies to locate the potential for terror will help in the development of integrated approaches for countering terrorism activities in buildings facing the highest risk of attacks, which is the main concern of the counter-terrorism units of fire departments.

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I hope that many people will reap benefits from this project's success and its future implementations.

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I. INTRODUCTION

The fire service has long studied, and with reasonable accuracy, predicted and responded to incidents of accidental fire and arson, both of which have a set range of "standard" characteristics that may be thought of as the "prototypical" fire response scenario. Most fires are started accidentally; in those cases, the fire department often receives information regarding the event before its arrival. Information en route, such as where the fire started, how the fire started, and what is burning, better enables responders to prepare and select the appropriate tools and means of suppression. When arson is involved, the same general principles apply, even though the fire may have (because of multiple ignition points, strategically chosen ignition points, or the use of accelerants) developed more significantly before effective fire response can be implemented. Moreover, arsons are typically perpetrated during the night hours, when most are asleep, which leads to reporting delays and incomplete information (including, for instance, the fact that the fire was a case of arson, which is generally not revealed until after the fact). Even so, although an arson fire may be more technically demanding or greater in scale than an accidental fire, it rarely constitutes a different kind of fire than the accidental fire. The arsonist generally does not sabotage fire suppression systems, jam the frequencies used by fire departments for on-site communications, or set booby-traps to prevent an effective fire response. In sum, fire departments are well equipped to handle arson fires.

The ability of fire departments to respond effectively to arson is not news, of course. Were fire departments not equipped to handle such fires, considerably fewer buildings would be dotting the skyline of any major city than there are now. However, a distinction can be drawn—and this thesis argues that a distinction must be drawn—between unsophisticated and sophisticated arson, between arson that has destruction as its goal and arson intended to serve some broader political end, between arson that is an opportunistic act and arson that is deliberately selected as the best possible means of causing deaths, killing or weakening first response organizations, and causing financial damage as a means of causing general fear.

Certain fires are deliberately ignited with the intent to harm life, and these fires fall outside the normal range of a fire emergency response. This type of arson has been referred to as pyro-terrorism, or the use of arson to advance a political or social objective (a term elaborated upon in Chapter II).[1] The Happyland fire in Bronx, New York, in March 25, 1990, was intentionally set with the intent to harm by lighting the fire in a location that blocked egress from the building, which resulted in 87 deaths.[2] This fire was not a terrorist attack, although it was a somewhat sophisticated act of arson, and it consequently has not received a great deal of attention from experts on terrorism. The Taj Mahal Hotel in Mumbai, India, in November 29, 2008, was subjected to a larger coordinated terror attack that took 164 lives. The attackers intentionally blew up the elevators and set fires on the lower floors to allow deadly smoke to percolate upward through the building.[3] In this instance as well, the commentary on the attack has mainly thought of the Mumbai attack as a terrorist attack that happened to involve the use of fire, without considering that this attack was *only possible* because fire was used. After victims were trapped in the hotel, the characteristics of the fire allowed it to be used to kill civilians throughout the building without the attackers setting bombs throughout. However, the literature does not reflect the emerging threat of which this is a symbol. Discussion has still not actually taken place concerning high-rise pyro-terrorism, or indeed pyro-terrorism at all.

When a fire is purposefully ignited to inflict great harm, the complexity of the fire-fighting task increases to the point that it may overwhelm the resources of the fire department. The pyro-terrorist employs a level of calculation that takes into account two central questions (as, of course, every terrorist does). First, the terrorist considers the characteristics of a target that make it valuable as a target. For the pyro-terrorist, this assessment includes factors like the occupancy of a building, the fuel load, the fire

[1] Robert Arthur Baird, "Pyro-Terrorism-The Threat of Arson Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction" (master's thesis, Marine Corps University, 2005), http://www.dtic.mil/dtic/tr/fulltext/u2/a509220.pdf.

[2] Richard W. Bukowski and Robert C. Spetzler, "Analysis of the Happyland Social Club Fire with Hazard I," *Journal of Fire Protection Engineering* 4, no. 4 (November 1, 1992): 117–130.

[3] A. H. Bhandarwar et al., "Surgical Response to the 2008 Mumbai Terror Attack," *The British Journal of Surgery* 99, no. 3 (March 2012): 368–372.

suppression systems both passive and active, the resources of local and nearby fire departments, and even traffic patterns. Since this type of fire event is carefully planned and executed, it can take advantage of vulnerabilities that may not have revealed themselves during less-sophisticated arsons and almost certainly may not become obvious during accidental fires, which of course, comprise the overwhelming majority of fires that occur. The fire countermeasure systems built into the building (e.g., sprinklers, standpipes, annunciator panels, and heating, ventilation, and air conditioning (HVAC) are likely to be compromised.

The pyro-terrorist works to sabotage these engineered systems and may ignite the fire at a location not readily accessible by responders. Since responders may not immediately recognize pyro-terrorism events, they may assume that such systems as standpipes are functioning normally. When these systems have been compromised, the fire response is impaired; either firefighters will delay their response to find another source of water, or they will reach the fire only to discover that they cannot combat it effectively because they do not have a water supply.

A historical study of incidents and open sources of data shows that terrorism using arson, in a broad view, tends toward the use of simplistic destructive methods, which although they have been proven dangerous, have not been comparable in casualty tolls to the damage done by the use of explosives. However, a major concern is that pyro-terrorism is emerging as its own category of attack and pyro-terrorists are becoming sophisticated who take advantage of the unique characteristics of fire as a weapon. Malicious groups and individuals have used an increasing number of fires across the world.[4] The aim of such acts is primarily directed toward driving political and social objectives while simultaneously coercing various governments. In the 2010s, the total number of incidents of pyro-terrorism has trended upwards and has caused significant damage and injuries. Whereas future pyro-terrorist attacks may seem to target city

[4] Allan Kahane, *Fire with Fire*, 1st. ed., stated ed. (Westport, CT: Pyro Publishing, LLC, 2006).

centers, the major threat remains to be forested areas.[5] Based on the occurrence of such attacks, the United States, France, and Israel are ranked as the most probable countries to experience pyro-terrorism attacks.[6] In Israel, for example, pyro-terrorism has long been employed; a 1996 study showed that it was responsible for about one-third of all Israeli fires.[7] In a report, the chief ranger of the Galilee region in Israel described his own experience with fighting arson, saying that fighting it was as challenging as fighting conventional terrorism.[8] This example simply demonstrates that arson is a viable terrorist weapon, and terrorists are likely to become more sophisticated in their use of arson just as they have become more sophisticated in their use of other weapons. Consider, by way of example, the iterative development of improvised explosive devices (IEDs) in the Middle East. At this point, terrorist organizations have the sophistication necessary to carry out highly effective terrorist attacks using homemade explosives. Similarly, it cannot be concluded that just because thus far arson terrorist attacks have been relatively unsophisticated, they will remain so in the future. It seems likely, in fact, that the opposite is true, and that firefighters must be prepared to grapple with this emerging threat.

Before September 11, 2001, the fire service, broadly speaking, was ill-equipped to respond effectively to high-rise terrorism events. Following the attacks on the World Trade Center, building codes and regulations were changed to improve the resiliency of buildings. Improved egress, fireproofing, backup water supplies, and communications are now required. Fire department training and standard operating procedures adjusted to address the emerging threat. However, even these changes have not prepared fire departments to respond to the unique dangers presented by sophisticated pyro-terrorism. Although some of the shortcomings of the fire response to acts of terrorism have been remedied at least in part, other gaps, including very serious omissions, remain and may

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[5] Stephen A. Raynis, "Improvised Incendiary Devices Risk Assessment, Threats, Vulnerabilities and Consequences" (master's thesis, Naval Postgraduate School, 2006), http://calhoun.nps.edu/handle/10945/2623.

[6] Earl Emerson, *Pyro: A Novel of Suspense* (New York: Ballantine Books, 2005).

[7] Nurit Kliot, "Forests and Forest Fires in Israel," *International Forest Fires News*, no. 15 (1996): 2–6.

[8] Ibid.

not reveal themselves in practice until further high-profile pyro-terrorism attacks against urban areas occur. By then, clearly, it will be too late.

For one example of a step in the right direction, consider the National Incident Management System (NIMS). Homeland Security designed and implemented NIMS, which is a system designed to handle large-scale events. The difficulty of managing resources increases in proportion with the size of the incident, which presents concerns for any large-scale terrorist attack, especially a pyro-terrorism attack.[9] NIMS provides a framework for maintaining accountability of crews for a given incident. Given the numbers and high motivation of terrorists, the fire service must continue to focus its attention on the emerging threat of pyro-terrorism. Despite the progress that has been made, concerns still exist unique to pyro-terrorism and the threat of sophisticated (as opposed to opportunistic) arson that have not been addressed. These topics are discussed in this thesis. In general terms, they relate to the possibility that fire counter-measures and response strategies will be sabotaged, circumvented, or even exploited by arsonists.

A. RESEARCH QUESTIONS

In an attempt to mitigate attacks on buildings, the prevalence of counter-terrorism response units within fire departments has increased.[10] In light of this trend, how do fire departments mitigate, prepare for, and respond to pyro-terrorism events in building structures? How should these strategies be improved?

B. DESIGN

The primary purpose of this thesis is to identify a new category of terrorist attack that is likely to emerge in the near future, a kind of attack against which the targets are not protected well (or indeed at all). This kind of attack is high-rise pyro-terrorism. This thesis discusses, first, the general concept of pyro-terrorism, and seeks to provide a definition of the concept that draws on Baird's pioneering work on the topic (and the

[9] "NIMS Frequently Asked Questions," Federal Emergency Management Agency, accessed July 28, 2017, https://www.fema.gov/nims-frequently-asked-questions.

[10] Baird, "Pyro-Terrorism-The Threat of Arson Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction."

work of others as well) to arrive at a definition consistent with the usage of the term in the literature and means something more than just "terrorism that happens to involve fire." By drawing a parallel between pyro-terrorism and cyber-terrorism, the author provides such a definition. Pyro-terrorism is terrorism that depends on the unique characteristics and capabilities of arson as a method of attack that enables attacks against targets that may not otherwise be so vulnerable or enable attacks to succeed that otherwise may have been intercepted by existing countermeasures. The parallel to cyber-terrorism should of course be obvious. Cyber-terrorism is terrorism that depends on the unique characteristics of the Internet, which facilitates entirely new kinds of attacks.

Although this thesis identifies future threats rather than confining itself to discussing attacks that have already occurred or attack modalities that have already proven effective when employed by terrorists, it is no work of imaginative fiction. Quite the contrary; it builds on existing literature discussing the use of arson in terrorism, and discussing arson and terrorism more generally to build a cohesive and well-sourced case for the importance of addressing pyro-terrorism as an emerging threat. This analysis proceeds in three parts. First, it is established that a gap exists in the literature concerning the plausibility or possibility of pyro-terrorism against high-rise buildings. Although it is perilously difficult to prove a negative, this thesis provides some assistance in this regard. The author points to the pioneering work of Baird, and to other scholars identifying his work as pioneering, to prove that pyro-terrorism—to say nothing of the specific category of high-rise pyro-terrorism—has not yet been explored. This analysis continues further. The author surveys work that has been done on terroristic arson, which is not quite the same as pyro-terrorism. He concludes, as suggested earlier, that pyro-terrorism as he has defined it has not yet really occurred, at least not as a weapon against high-rise buildings, and that a gap can be found in the literature as to the possibility of its use.

This thesis is thus situated firmly within the literature as a speculative work identifying future threats. To state so is not, as some suggest, is to say that it is useless or

even counterproductive.[11] Quite the contrary, terrorists are aware of the potential that pyro-terrorism holds (at least, some kinds of pyro-terrorism), and that they have simply avoided using it to any great extent thus far. Even though pyro-terrorism against urban targets has not been discussed by terrorist organizers, nor has it yet been employed to great effect by organized terrorist groups, it remains the case that it is not likely to be news to terrorists, and can only serve to improve the status quo of laxity rather than to expose this nation to a new threat. To understand why this is the case, it is only necessary to consider the perspective of a terrorist seeking a new attack vector vis-à-vis the perspective of an agency seeking to prevent it. The terrorists, it seems, have a lower standard for taking action. They require that their target sound plausible rather than a certain success. To see proof, look no further than the enormous number of terrorists who fail to attain their objective (often dying) or, even more often, are foiled before they leave the planning stage. The frequency of such failures does not appear to have dissuaded others from following in their footsteps. Terrorists, then, do not need a master's thesis to inspire an attack; it is enough that others have carried out similar attacks before (e.g., the Korean subway attack).

The agency, by contrast, has a limited budget, the resources with which to carry out cost-benefit analyses, and an obligation to maximize the effectiveness of its budget, an obligation that demands that resources be allocated only to proven threats, or at least to possibilities for which a very strong argument can be made. Thus, such an agency demands something more than just the existence of prior similar attacks; it demands a coherent and well-sourced argument that a pressing vulnerability exists in need of protection. To argue another way, to suggest that the sort of thesis that this author has written aids terrorists is to suggest either that nobody has ever used fire to cause mass civilian casualties in urban environments (which has been previously shown to be utterly false) or else to suggest that terrorists are more motivated by the current state of academic literature than they are by past examples of attacks that they can find with little effort. Alternatively, to suggest that theses like this one are unhelpful is to suggest that security

[11] Dallas Boyd, "Protecting Sensitive Information: The Virtue of Self-Restraint," *Homeland Security Affairs* 7, no. 1 (2011), http://search.proquest.com/openview/29273935064a3138f13d2859f28a4af2/1?pq-origsite=gscholar&cbl=1336360.

agencies have such a robust internal mechanism for identifying future threats that they are already aware of attack modalities like the one discussed in this thesis, and as such, the only purpose the thesis can possibly serve is to alert attackers to a new potential weapon. However, this concept is plainly false, as is seen from so-called "failures of the imagination" that lead to successful terrorist attacks like the 9/11 hijackings.

This thesis is valuable, ultimately, because it identifies an attack method that can very plausibly be employed by terrorists; an attack method that has not thus far been guarded against in any systematic way. Where efforts have been made to guard against arson, this thesis discusses why those efforts may not suffice to prevent sophisticated attackers from successfully completing a planned attack. Most of those efforts, as has been discussed, focus on the prevention of arson and accidental fires rather than on the prevention of deliberate attacks calculated to overcome passive and even active countermeasures. This scenario, of course, is rather like trying to prevent hijackings by making sure that planes do not spontaneously fall out of the sky and that passengers cannot suborn the flight crew by yelling loudly at them. As the 9/11 hijackings showed, countermeasures that may be sufficient to discourage an opportunist are in many cases barely an inconvenience to a determined attacker, especially an attacker willing to risk or abandon his own life in the completion of an attack.

In addition to discussing the inadequacy of some current efforts to guard against arson, this thesis examines the current state of the literature and provides very thorough coverage of topics relevant to the overall question of high-rise pyro-terrorism for two reasons. First, the academic community thus far has neglected the threat identified in this thesis. As a result, a cohesive body of literature about high-rise pyro-terrorism (or even about pyro-terrorism, apart from a few outliers) can definitely provide the academic reader or the practitioner with an understanding of the topic sufficient to engage with the recommendations and concerns presented in this thesis. The central contribution of this thesis to the academic conversation concerning pyro-terrorism is to identify a new category—high-rise pyro-terrorism—and draw on rich bodies of scholarly literature relating to fire safety in general, the tactical mitigation of high-rise fires, the historic relationship between arson and pyro-terrorism, the potential for sabotage that overcomes

passive fire countermeasures, and so on to allow those rich bodies of literature to serve a supporting role in the development of this new topic.

This thesis uses data sources in the area of pyro-terrorism, building construction and design, fire suppression systems, and emergency response. The literature examining pyro-terrorism specifically is very sparse, which is itself a problem and also poses challenges for this literature review. Consequently, this thesis integrates the literature that currently exists regarding the use of arson as a tool for terrorism and unmotivated, unprincipled destruction, the literature on the mitigation of building fires (especially arson) and the vulnerabilities and deficiencies of technologies and methodologies used for that mitigation, and the literature on tactical mitigation of high-rise fires and especially terroristic high-rise fires (insofar as such literature exists). Where necessary, literature that sets out a general point about fire safety unrelated to terrorism is supplemented with literature that relates specifically to terrorism but does not examine fire safety in an attempt to synthesize the two. A review of publications and studies in the area of building construction and design provides greater insight into mitigation design. This literature review also provides information that can be applied by emergency responders to understand the threat of pyro-terrorism and to develop appropriate responses.

The intended contribution of this research is that it synthesizes information from a wide range of fields. This approach allows a thesis based on secondary data sources to contribute substantially still to the literature by hollowing out an entirely new topic out of the existing literature. The scope of this study is limited to the study of fire-related terrorism. Literature related to fire, building safety, terrorism, and the potential for arson as a terrorist weapon are all considered. By understanding the nature and the risk of pyro-terrorism, it is possible to draw conclusions that may be useful in improving high-rise and emergency responder safety. The boundaries of this study are the investigations of pyro-terrorism use as a weapon of terror.

This literature-oriented approach also provides insight into pyro-terrorism, specifically related to the use of fires as weapons. Concerning information retrieved from past occurrences of such attacks, this thesis offers a holistic framework that expands the

countermeasures taken to address this kind of threat.[12] The approach adopted in this thesis is a qualitative rather than a quantitative analysis of the problem of pyro-terrorism. Based on the information evaluated in the chapters, this thesis provides practical recommendations about the most important factors affecting life safety and the economic damage that arsonists may be able to inflict. These recommendations include the identification of building materials or fire countermeasures especially vulnerable to sabotage and the use of alternative building methods or else a level of redundancy that can prevent sabotage from being effective, the use of communications methods robust enough to survive jamming attempts and network saturation, and the development of a framework within which first responders can coordinate with intelligence agencies to facilitate the sharing of sensitive information without compromising successful counterterrorism efforts. The author believes that practitioners should implement these recommendations immediately while the literature catches up to this emerging threat by exploring other ways of mitigating pyro-terrorism. Each chapter also identifies gaps in the literature suitable to serve as a guide to academic engagement with this topic.

C. OVERVIEW

Chapter II describes the historical and modern distinction between arson, as a relatively unprincipled act of destruction, and pyro-terrorism, as the reasoned use of fire as a political weapon. The chapter examines the history of arson as a weapon of terrorists and describes the distinction between terrorism that happens to involve arson and genuine pyro-terrorism. The former category describes the majority of terrorist arson that has occurred thus far, which is explained by the nature of arson as the weapon of choice of opportunists (not requiring the expertise to build bombs or anything of that nature; in other words, everyone can burn a house down, but it takes time and skill to blow it up). This chapter also explores the extent to which pyro-terrorism is a new category previously undescribed in the literature, concluding that it is in fact a new category that has not been adequately explored previously. In addition to this theoretical work, the chapter also discusses the reasons to believe that arson, as a specific weapon employed

[12] Peter Lance, *1000 Years for Revenge: International Terrorism and the FBI—The Untold Story* (New York: HarperCollins e-books, 2009), loc. 77 of 560, Kindle.

for calculated reasons against urban targets, is likely to become a serious threat in the coming years. It explores past attacks that were not properly terrorist incidents but nevertheless demonstrated the capabilities of an attacker who notices a vulnerability in a high-density area and used fire as a weapon to exploit that vulnerability.

Chapter III describes the historical evolution of fire safety codes as they relate to resistance to intentional, as opposed to accidental, fire damage. It also discusses how this evolution has and ought to continue further in the face of pyro-terrorism as distinct from arson. The guiding principle of this chapter is the division of codes into two categories, prescriptive and performance-based. The position best supported by the literature is that prescriptive codes are inefficient and may actually encourage suboptimal design where technology has advanced enough to allow greater safety using new methods. The chapter advocates for a hybrid performance-prescription code that sets out performance standards significantly higher than the current status quo, but allows as an alternative that new developments adhere to a set of relatively standard prescriptions. This chapter then proceeds to discuss the ways that new technological advancements affect resistance to pyro-terrorism, and how current ways of evaluating fire safety may not be adequate for describing the threat posed by a determined and sophisticated arsonist. It also describes some general concerns related to the construction of buildings to resist fire, like the use of timber in high-rise buildings and the potential exposure to sabotage that certain kinds of insulated panel have.

Chapter IV discusses the historical evolution of fire response procedures, the current state of the art as it relates to high-rise fires, and how those procedures have changed and ought to change to respond to the threat of arson that targets the emergency responders. Some of the author's concern is with the basic structure of the fire department, and whether the risk of pyro-terrorism suggests that increasing standards of professional capability may need to be imposed on firefighters in high-risk areas, but his main concerns are tactical and not organizational. He explores in some detail, for instance, the methods by which firefighters can secure lines of tactical communications in the face of sabotage or simple overuse (as may be the case even when a terrorist does not set out to overwhelm communications lines). He also discusses the problem of

information sharing between fire departments and other departments, especially those with sensitive counter-terrorism information. A somewhat odd question that nevertheless is cause for significant worry, in the author's opinion, is the use of high-speed elevators for high-rise evacuation. On its face, it seems like a good idea, notwithstanding the fact that it goes counter to the prevailing wisdom. However, as this chapter discusses, although such a strategy may be successful in the ordinary case of high-rise fires, it may also be vulnerable to disruption or even exploitation by attackers.

II. PYRO-TERRORISM AND ARSON

The purpose of this chapter is to outline the historical development of arson and pyro-terrorism. Since pyro-terrorism is an emerging term that has not yet seen a great deal of examination and scholarly engagement, it still does not have a consensus definition. The difficulty of separating ordinary violence from terrorism is exacerbated in the case of pyro-terrorism. In the absence of an explicit endorsement of an act of arson by a terrorist group, or contextual clues indicating overwhelmingly a relationship between the act of arson and a political goal served by the creation of terror, it may be impossible to tell whether a particular attack is pyro-terrorism or "mere" arson. Similar difficulties arise in demarcating the line between arson and pyro-terrorism.

A discussion of the history and development of pyro-terrorism and its distinctions from the use of arson in simple interpersonal violence, property destruction, and especially political sabotage is beneficial in the following chapters when discussing regulatory and tactical mitigation of pyro-terrorism. Thus, this chapter begins by discussing the distinction between terrorism and violence generally, because such a distinction serves as the foundation for any distinction between pyro-terrorism and arson. This chapter then addresses the historical emergence of pyro-terrorism as a distinct category of arson, using contrasting cases of politically motivated arsons that were not acts of terrorism to highlight the distinctions between arson and pyro-terrorism. The bulk of this discussion specifically focuses on the history of pyro-terrorism. Also of interest are cases in which pyro-terrorism may have been used but was not, and on what those cases may reveal about the circumstances under which pyro-terrorism may be used.

This chapter then proceeds to a discussion of emerging concerns about pyro-terrorism. Such concerns primarily revolve around the possibility that pyro-terrorism represents a distinct category of terrorism (akin to cyberterrorism in that regard) with its own set of vulnerabilities and requiring its own countermeasures. Thus, far, discussion of pyro-terrorism as a distinct emerging threat has focused on the possibility of arson-caused wildfires; however, much of this discussion proves relevant to the author's broader thesis concerning pyro-terrorism in high-rise buildings. Another emerging concern examined in

this chapter is the possibility of terrorist attacks targeting first responders. The challenges associated with identifying early on a case of pyro-terrorism (which is much more difficult than identifying terrorism in a case in which, for example, an explosive is used) make first responders to arson in high-rise buildings acutely vulnerable to such attacks.

A. THE DISTINCTION BETWEEN TERRORISM AND VIOLENCE

In general, terrorism is distinguished from ordinary violence in several ways, which are relatively uncontroversial. This thesis draws on a RAND Corporation report by Brian Jenkins on the definitional challenges to the study of terrorism.[13] Although an accepted definition of terrorism suitable for rigid legal application is not yet available, and unanimity on what constitutes terrorism and what does not is also not yet defined, widespread agreement has been reached on what qualities are "terrorism-esque." In other words, terrorism is much like Justice Stewart's infamous reasoning in an obscenity case, there may be no single accepted definition, but one knows it when one sees it.

First, terrorism is motivated by political concerns.[14] This criterion may pose some challenges considering that "the personal is political," and that no interpersonal interactions occur without a political dimension, but it is a criterion that becomes clearer considering paradigmatic cases of terrorism and not-terrorism. Where an act of violence is part of a larger pattern of violent acts addressed to a faceless and generalizable group, for instance, it seems uncontroversial that it is terrorism even if it is motivated in part by interpersonal hostility (for instance, if any of the church arsons described in this chapter were carried out in part because the arsonist had a personal dislike for members of the church he burned). Where an ideological conflict or bigoted hatred merely serves as the backdrop for a purely interpersonal and individualized conflict, as may occur when a racist, motivated by racist concerns of blood purity, murders an interracial couple, this event is generally called a hate crime instead of an act of terrorism. This distinction

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[13] Brian Michael Jenkins, *The Study of Terrorism: Definitional Problems* (Santa Monica: RAND, 1980), http://www.dtic.mil/docs/citations/ADA103363; Cástor Miguel Díaz-Barrado, "The Definition of Terrorism and International Law," in *International Legal Dimension of Terrorism*, ed. Pablo Antonio Fernández-Sánchez (Leiden, Boston: Martinus Nijhoff Publishers, 2008), 27–42.

[14] Jenkins, *The Study of Terrorism: Definitional Problems*.

becomes easier to understand when it is considered in the context of other factors, like the provocation of publicity.

The second factor characteristic of terroristic violence is that it is carried out against civilians.[15] Two things are important to keep in mind. First, "civilians" are defined very broadly to include government officials, even law enforcement officers. Second, the inclusion of military or political targets does not prevent an attack from being considered an act of terrorism, so long as it was designed to cause a large number of civilian casualties. The 9/11 hijacking that targeted the Pentagon comes to mind. Even taken in isolation, such a hijacking would unquestionably be an act of terrorism because of the deaths of the civilians on the plane; had the attack on the Pentagon also used a truck bomb or unoccupied plane, it would instead be more akin to an act of guerilla warfare, being an attack on a military target with at most incidental civilian casualties.

Further, terrorist attacks are intended to provoke maximum publicity.[16] This goal dovetails with the final and probably defining criteria that terrorist violence is intended to create fear. To elicit fear and project an image of strength, terrorists seek to cause deaths and destruction in an attention-attracting way, whether through the use of unusual methods (for instance, the Japanese sarin gas attacks), attacking high-profile targets (for instance, the 9/11 hijackings), or the infliction of a significant number of casualties (the Oklahoma City bombing).[17]

Finally, terrorist attacks are intended to provoke fear—usually fear of the terrorist, who often claims responsibility publicly—that has impacts far greater than the act itself.[18] The relative magnitude of the fear created as opposed to the tangible impacts of the violence is most important. Terrorism is an archetypical strategy of a materially weak

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[15] Jenkins, *The Study of Terrorism: Definitional Problems*; Brian Michael Jenkins, "New Challenges to U.S. Counterterrorism Efforts: An Assessment of the Current Terrorist Threat," *CT-377 Testimony to Senate Homeland Security and Governmental Affairs Committee* 11 (2013), https://www.ncjrs.gov/App/Publications/abstract.aspx?ID=261142.

[16] Jenkins, *The Study of Terrorism: Definitional Problems*.

[17] Yasufumi Asai and Jeffrey L. Arnold, "Terrorism in Japan," *Prehospital and Disaster Medicine* 18, no. 2 (April 2003): 106–114.

[18] Ibid.

organization; it is propagandistic political warfare. Were it otherwise, the organization could use more conventional means to achieve its goals. An entity like Al Qaeda could never cause enough physical damage in the United States to alter seriously the American way of life. The fear created by terrorism consequently serves as a sort of force multiplier; the uncertainty created in citizens of the targeted city, state, or country makes up for the material weakness of the terrorist.[19] Terrorist attacks are intended to overstate the strength of the terrorist group to create the fear that further attacks cannot be prevented.

B. THE HISTORICAL DEVELOPMENT OF PYRO-TERRORISM OUT OF ARSON

Many of the scholars relied on in this portion of the chapter do not use the term "pyro-terrorism" to describe arson employed to terroristic ends, but such a delineation is not essential for the purpose of this section. What is important, rather, is understanding the circumstances under which the label of terrorism is appropriate for an act of arson.

1. The History of Arson

Arson—even for political ends—of course has a history that goes beyond the recognition of its utility for terrorism. For a very long period of human history, fire was the most destructive force that man could harness, and was so employed in warfare, in interpersonal disputes, and for political violence. However, arson is not often marked by the qualities, discussed previously, that distinguish violence from terrorism.

In many cases, arson is simply a lower-risk, less impressive, and consequently, "less aggressive" alternative to bombing, and although it is often politically motivated, it is consequently less likely to be part of a coherent campaign of terror.[20] Arson is less risky for the arsonist for a number of reasons. The materials with which arson is accomplished are readily available. They are so readily available, in fact, that it is

[19] Asai and Arnold, "Terrorism in Japan," 106–114; Peter Gordon et al., "The Economic Impacts of a Terrorist Attack on the U.S. Commercial Aviation System," *Risk Analysis: An Official Publication of the Society for Risk Analysis* 27, no. 3 (June 1, 2007): 505–512.

[20] Albert A. Stahel, "Switzerland: Terrorism and Its Control," *Terrorism and Political Violence* 4, no. 4 (December 1, 1992): 206–209.

actually impossible to determine who has access to the materials necessary to commit arson. Almost every adult, simply by virtue of having an automobile, has a great deal of gasoline available at a moment's notice; moreover, a napalm-like sticky fuel can be produced by the addition of polystyrene to gasoline.[21] No special expertise is required to produce fuel-soaked rags or even Molotov cocktails; nor are these weapons conspicuously criminal as are homemade explosive devices; nor do inexperienced arsonists expose themselves to great risk in producing the materials needed for the arson.

Even a significant arson will generally not inspire as much fear as a comparably destructive explosive attack. Fire, as a destructive force, is one that most adults are intimately familiar with and understand its risks and are also aware of the existence of a response force proficient in mitigating those risks. Moreover, the fact that a fire is the result of arson is not ordinarily obvious to observers until the fire has been resolved and carefully investigated. The immediate gut impact of a bombing is not present. For these reasons, arson is likely to be used in apolitical violence sprees, far more so than is bombing.[22]

Even where attacks are clearly political, against civilian targets, and intended to create publicity, it has been argued that many cases of political arson, even as part of a concerted campaign, are not terrorism but mere sabotage.[23] Apologists for the Animal Liberation Front (ALF), for instance, commonly use this argument. Beginning in approximately 1980, the United Kingdom was plagued by fire-bombings by the ALF.[24] The campaign, broadly understood, was plainly terroristic. Executives of companies that the ALF had targeted were visited in their homes and threats were made against their families; products tested on animals were poisoned. The ALF has used extensive fire

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[21] John Pike, "Napalm," Global Security.org, accessed August 14, 2017, http://www.globalsecurity.org/military/systems/munitions/napalm.htm.

[22] Pekka Santtila, Katarina Fritzon, and Anna Lena Tamelander, "Linking Arson Incidents on the Basis of Crime Scene Behavior," *Journal of Police and Criminal Psychology* 19, no. 1 (March 1, 2004): 1–16.

[23] David Thomas Sumner and Lisa M. Weidman, "Eco-Terrorism or Eco-Tage: An Argument for the Proper Frame," *ISLE: Interdisciplinary Studies in Literature and Environment* 20, no. 4 (December 1, 2013): 855–876.

[24] Rachel Monaghan, "Not Quite Terrorism: Animal Rights Extremism in the United Kingdom," *Studies in Conflict and Terrorism* 36, no. 11 (November 1, 2013): 933–951.

bombings against civilian targets that it believed contributed to the exploitation and torture of animals. However, these arsons were generally calculated so as not to jeopardize human life.[25] For this reason, although the ALF has committed acts of terrorism, the arsons themselves probably should not be understood as terroristic.

Similarly, with respect to the Earth Liberation Front (ELF), arson has often been a precursor to genuine terrorism rather than terrorism itself.[26] Beginning in about 1996, the ELF has used arson as part of its portfolio of violent tactics, although the suitability of the term "terrorism" is disputed.[27] For theorists advancing the position that terrorism is an inapposite term, the critical differentiator between sabotage and terrorism is that sabotage is not intended to harm human lives, whereas terrorism is.[28] Although this definition may not be tenable with respect to terrorism more broadly, the common use of arson in destructive sprees, sabotage, and even insurance fraud, suggests that this thesis should adopt such a distinction.

2. The History of Pyro-terrorism

Arson has never been understood as a phenomenon separate from terrorism; it has never been the case that an act can be *either* arson or terrorism, but not both.[29] Rather, the possibility that arson can be a method used in terrorism has been considered since long before pyro-terrorism began to be analyzed as a discrete topic with a distinct name.[30] Generally speaking, political arson has been considered distinct from pyro-terrorism in

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[25] Monaghan, "Not Quite Terrorism: Animal Rights Extremism in the United Kingdom," 933–951.

[26] Gary A. Ackerman, "Beyond Arson? A Threat Assessment of the Earth Liberation Front," *Terrorism and Political Violence* 15, no. 4 (October 1, 2003): 143–170.

[27] Stefan H. Leader and Peter Probst, "The Earth Liberation Front and Environmental Terrorism," *Terrorism and Political Violence* 15, no. 4 (2003): 37–58, http://www.tandfonline.com/doi/abs/10.1080/09546550390449872.

[28] David Thomas Sumner and Lisa M. Weidman, "Eco-Terrorism or Eco-Tage: An Argument for the Proper Frame," *ISLE: Interdisciplinary Studies in Literature and Environment* 20, no. 4 (December 1, 2013): 855–876.

[29] Kadir Akyuz and Todd Armstrong, "Understanding the Sociostructural Correlates of Terrorism in Turkey," *International Criminal Justice Review* 21, no. 2 (May 12, 2011): 135.

[30] Robert Arthur Baird, "Pyro-Terrorism—The Threat of Arson-Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction," *Studies in Conflict and Terrorism* 29, no. 5 (August 1, 2006): 415–428.

cases where it is not employed as part of a broader campaign of terror or in which it is not intended to jeopardize human life. This section turns from considering cases in which the moniker of pyro-terrorism is inappropriate to cases in which it is warranted.

a. Opportunistic Pyro-Terrorism

The American South in the 1990s saw a spate of hundreds of arsons against African-American churches.[31] These arsons, insofar as it was possible to identify the perpetrators, were often linked directly to white supremacist groups like the Ku Klux Klan (KKK); however, they were also often the product of "lone wolves" inspired by the trend of arsons to carry out one of their own. However, Black churches were targeted with other kinds of violence as well. Bombings were also used, and these arson attacks appear to reflect, more than anything else, a predilection of certain terrorist groups to use arson as opposed to other means.[32] Studies of the church arsons suggest strongly that the selection of a particular method of carrying out terrorist attacks is not a purely rational one but is rather heavily influenced by socio-cultural context.[33] Church arsons were more common in areas with an already high arson rate. The contrast between arsons and bombings suggests that this effect is not merely the result of some areas having higher crime rates than others.[34]

A similar example is the rise in seemingly random arson attacks in Germany in the 1990s carried out by right-wing nationalists.[35] These attacks occurred during a series of anti-immigrant riots and widespread violence.[36] The arsons were disorganized and appeared not to be associated with any concrete political demands or a specific set of goals. Although a unifying factor was that the perpetrators were right-wing

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[31] Sarah A. Soule and Nella Van Dyke, "Black Church Arson in the United States, 1989–1996," *Ethnic and Racial Studies* 22, no. 4 (January 1, 1999): 724–742.

[32] John P. Bartkowski, Frank M. Howell, and Shu-Chuan Lai, "Spatial Variations in Church Burnings: The Social Ecology of Victimized Communities in the South," *Rural Sociology* 67, no. 4 (2002): 578–602.

[33] Ibid.

[34] Soule and Van Dyke, "Black Church Arson in the United States, 1989–1996," 724–742.

[35] Audrey Kurth Cronin, "Behind the Curve: Globalization and International Terrorism," *International Security* 27, no. 3 (January 1, 2003): 40.

[36] Roger Karapin, "Antiminority Riots in Unified Germany: Cultural Conflicts and Mischanneled Political Participation," *Comparative Politics* 34, no. 2 (2002): 147–167.

ethnonationalists, they were not linked by membership in any organization; their commonalities were solely ideological. In sum, the attacks were opportunistic, not calculated.

b. Calculated Pyro-Terrorism

Calculated pyro-terrorism is fire that is selected as the means of violence for reasons that are thought-out and relate to the effectiveness of the terrorist attack rather than the convenience of carrying out such an attack. The primary marker of "calculation" in terrorism is a high degree of commitment to a single attack, or small number of related attacks, rather than an ongoing campaign of terror.[37] For example, suicide attacks generally evince a great degree of calculation because they represent the individuals' total commitment to the cause for which they fight.[38] Moreover, attacks that exhibit a high degree of planning (the coordination of the Madrid and London bombings; the difficulty involved in procuring sarin gas in Tokyo) are quite clearly calculated rather than opportunistic.

The absence of such calculated pyro-terrorism is conspicuous precisely because arson is a relatively "safe" form of terrorism for the terrorist.[39] When arson is likely to be an effective means of causing mass casualties, economic harm, or some other goal, a rational terrorist likely prefers arson to other means, like biological terrorism.[40] In other words, most attacks should be expected that *can* be committed using fire actually to be committed that way. Yet, historically, it has not been the case. Considering major terrorist attacks that either have actually occurred and might have been accomplished through the use of arson, or that have been proposed but have not been carried out, the

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[37] Martha Crenshaw, "The Strategic Logic of Terrorism," in C*onflict after the Cold War: Arguments on Causes of War and Peace*, ed. Richard K. Betts (New York: Routledge, 2017): 461.

[38] Scott Atran, "The Moral Logic and Growth of Suicide Terrorism," *The Washington Quarterly* 29, no. 2 (March 1, 2006): 127–147; Hafez, Mohammed M. "Dying to Be Martyrs: The Symbolic Dimension of Suicide Terrorism," in *Root Causes of Suicide Terrorism: The Globalization of Martyrdom*, ed. Ami Pedahzur (London: Routledge, 2006), 54.

[39] Albert A. Stahel, "Switzerland: Terrorism and Its Control," *Terrorism and Political Violence* 4, no. 4 (December 1, 1992): 206–209.

[40] See the discussion of the relatively low risk to the arsonist, as compared to more involved and impressive attacks like biological attacks and bombings.

author finds a pronounced preference among terrorists (at least thus far) for other means of violence.

A major example in the former category is the targeting of subway systems in Asia using biological weapons. Despite the high vulnerability of subway systems to fire, terrorism against subway systems, where it has occurred, has been primarily biological.[41] This point is astonishing considering that arson against subway systems in Asia has been an enormously effective form of violence in producing mass casualties.[42] In 2003, a lone wolf in South Korea filled milk cartons with fuel and set them alight, killing more than a hundred people in the Daegu subway. This attack required little preparation or planning and required no expertise. By contrast, the 1995 sarin gas attack in Tokyo, although it injured thousands, killed only 12.[43] In 2004 in Madrid, similarly, subway systems were attacked with explosives rather than with arson; killing almost 200, but these blasts were coordinated attacks against multiple subway systems rather than a single attack. In 2005 in London, the coordinated 7/7 bombings targeted the subway and killed 56. A simple casualty count is clearly not the be-all end-all of retrospective analysis, but it does suggest that the means adopted by the Madrid, London, and Tokyo attackers were not inherently more effective than arson.

It may be protested, with reason, that the Tokyo attackers accomplished far more using a novel and terrifying means of violence (biological weapons) than they would have through more conventional means. Even granting that this fact is true, still remaining is the fact that arson is at least as effective a weapon as sarin or explosives, and the puzzle of why it has not been employed against subway systems by terrorists.

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[41] Mei Xiu-juan, "Study on Fire Scenarios Characteristic for Subway Trunk Arson Simulation Test [J]," *Journal of Safety Science and Technology* 3 (2011): abstract; Yasufumi Asai and Jeffrey L. Arnold, "Terrorism in Japan," *Prehospital and Disaster Medicine* 18, no. 2 (April 2003): 106–114.

[42] Dae-Kyoon Park et al., "The Role of Forensic Anthropology in the Examination of the Daegu Subway Disaster (2003, Korea)," *Journal of Forensic Sciences* 54, no. 3 (May 2009): 513–518.

[43] Asai and Arnold, "Terrorism in Japan."

More generally, large-span commercial buildings are extremely vulnerable to arson and are generally densely populated.[44] However, they, too, are generally targeted by explosive attacks rather than by arson.[45] A search of the literature to find arsons against shopping malls and other large commercial complexes was fruitless, whereas explosive attacks against commercial complexes are relatively common. A Western reader may intuit that this result means that fire may not actually be an effective weapon in, for example, a shopping mall, but this assumption is incorrect. High-density commercial spaces (convention centers, nightclubs, megachurches, malls) are extremely vulnerable to fire because of the difficulty of evacuating them and because the efficacy of initial response systems like sprinklers has been dramatically overestimated.[46] If evacuation and containment methods prove insufficient, a review of historical building collapses as a result of fire indicates that arson may actually be more effective than bombing in producing mass casualties.[47]

c. Arson as a Unique Terrorist Strategy

The second category of surprising data is discussed next. Some attacks can theoretically be carried out using arson but not through other, more "traditional," terrorist methods.[48] An example is the use of arson to cause forest fires. It seems likely that such attacks can be effective.[49] Several speculative articles have been published arguing that

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[44] Su Jin Woo and Eun Kyoung Hwang, "A Study on the Evacuation Characteristics of Large-Span Structures Buildings," *Applied Mechanics and Materials* 638–640 (2014): 1977–1981. Large-span buildings are especially wide and are not supported with load-bearing supports on the interior. The paradigmatic example is an aircraft hangar.

[45] Roderik Mrena et al., "Otologic Consequences of Blast Exposure: A Finnish Case Study of a Shopping Mall Bomb Explosion," *Acta oto-laryngologica* 124, no. 8 (October 2004): 946–952; M. Stein and A. Hirshberg, "Medical Consequences of Terrorism. The Conventional Weapon Threat," *The Surgical clinics of North America* 79, no. 6 (December 1999): 1537–1552.

[46] Woo and Hwang, "A Study on the Evacuation Characteristics of Large-Span Structures Buildings."

[47] Jesse Beitel and Nestor Iwankiw, "Historical Survey of Multistory Building Collapses Due to Fire," *Fire Protection Engineering* 27 (2005): 42.

[48] See, e.g., Nick Deshpande, "Pyro-Terrorism: Recent Cases and the Potential for Proliferation," *Studies in Conflict and Terrorism* 32, no. 1 (January 23, 2009): 36–44.

[49] Baird, "Pyro-Terrorism—The Threat of Arson-Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction."

pyro-terrorism is an under-appreciated threat.[50] Most prominent among these is Baird's 2006 article, "Pyro-Terrorism—The Threat of Arson-Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction." The thesis of this article, and of follow-up work by Deshpande and others, is that wildfires pose the risk of enormous economic damage, can be set with comparatively little risk to the terrorist, and require little expertise, imagination, or guidance to use effectively. That arson-induced wildfires can cause extreme economic damage should be self-evident. Each year, forest fires along the American west coast cause enormous financial damage, and those fires are not strategically set but rather the accidental product of very dry conditions. The damage caused by wildfires strategically set to maximize impact is of course likely to be much greater. The threat posed by wildfires deliberately set to cause maximum impact is substantial; a wildfire with carefully chosen ignition points can be more than twice as damaging as a naturally occurring fire.[51] The ease of setting wildfires as opposed to carrying out other kinds of terrorist attacks has already been discussed in this chapter, and as such, the other points Baird makes in support of his position are not belabored.

Baird's article, and others along the same line of thought, has garnered a great deal of attention in part because of the significant economic threat posed by wildfires, which exceeds that of arson against buildings.[52] Mitigating the threat presented by wildfires is a key concern for landowners in fire-prone areas, and the seeming inevitability of the attack vector that Baird proposes has led to intense speculation about the true costs of such terrorism and whether it can be prevented.[53] The theoretical concerns about pyro-terrorism, which have smoldered since Baird's pioneering article on

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[50] Baird, "Pyro-Terrorism—The Threat of Arson-Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction"; Deshpande, "Pyro-Terrorism: Recent Cases and the Potential for Proliferation"; Jason S. Gordon et al., "Wildfire Terrorism Risk Assessment and Management: A Pilot Study," *Forest Economics and Policy in a Changing Environment: How Market, Policy, and Climate Transformations Affect Forests* (2016): 94.

[51] Eghbal Rashidi, "Optimization Models and Algorithms for Vulnerability Analysis and Mitigation Planning of Pyro-Terrorism" (PhD diss., Mississippi State University, 2016), http://search.proquest.com/openview/e4113de410377537da5b4b509c14823b/1?pq-origsite=gscholar&cbl=18750&diss=y.

[52] Georgios Boustras and Nikolaos Boukas, "Forest Fires' Impact on Tourism Development: A Comparative Study of Greece and Cyprus," *Management of Environmental Quality: An International Journal* 24, no. 4 (2013): 498–511.

[53] Deshpande, "Pyro-Terrorism: Recent Cases and the Potential for Proliferation."

the topic, have been ignited by a very real conflagration in Israeli forests, a fire that was deliberately started as an act of terrorism against the state.[54] Although fire has long been a weapon employed by Palestinian militants against Israel, this most recent case has served to drive home the argument that pyro-terrorism is likely to become a serious aspect of terrorism in the coming years.

However, despite the ease and potential harms of wildfire arson, anti-American terrorists have not adopted this approach.[55] A simple desire to cause harm in the ways in which a target is most vulnerable strongly suggests so-called "homegrown jihadists" plan to use arson to cause wildfires; however, evidence suggests that they have not done so; although Al Qaeda and other terrorist organizations that have invested in producing homegrown jihad have explicitly condoned wildfire arson as an "efficient" form of terrorism. Marsden et al. conclude, "those jihadists who do move to physical action are not deterred by concerns about taking human life or about personal safety; or to put it differently, those with similar sympathies who are so constrained are seldom if ever attracted by lower-cost alternatives."[56]

At least one counterexample to the proposition that terrorists have not used wildfire arson as a weapon can be presented.[57] In Israel, severe wildfires have been attributed to Palestinian militants, and these wildfires have caused enormous damage (on the order of thousands of homes destroyed). However, patterns of Palestinian-Israeli conflict are distinct from patterns of terrorist behavior in other parts of the world, and it may be more accurate to describe any Palestinian attacks of this nature as military actions rather than as acts of terrorism (not because of any value judgment on the conflict, but

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[54] János Besenyő, "Inferno Terror: Forest Fires as the New Form of Terrorism," *Terrorism and Political Violence* (July 11, 2017): 1–13.

[55] Sarah Marsden, Daiana Marino, and Gilbert Ramsay, "Forest Jihad: Assessing the Evidence for 'Popular Resistance Terrorism,'" *Studies in Conflict and Terrorism* 37, no. 1 (January 2, 2014): 1–17.

[56] Ibid., 15.

[57] Besenyő, "Inferno Terror: Forest Fires as the New Form of Terrorism," 1–13; Ariel Schalit, "Wildfire Blamed on 'Terror' Roars through Israeli City," *AP News*, November 24, 2016, https://apnews.com/d7a18c88fa6341b296e30c4d5b5120d4.

rather because of the shooting war between Palestinian militants and the Israeli armed forces).[58]

d. Patterns of Pyro-Terrorism

The examples and analysis provided in this section illustrate several salient points, both in terms of patterns of terrorist behavior and in terms of the way that pyro-terrorism should be structured and understood. The conclusion that seems most strongly supported by the former discussion is that pyro-terrorism has thus far been predominantly limited to attacks of opportunity as part of disorganized campaigns of terror; where it has been used in an organized way, it is at least arguable that its use constitutes sabotage rather than actual terrorism. With respect to these arsons of opportunity, the previous examples show that the use of arson in terrorism has historically been associated with the use of arson in "ordinary" crimes. Arson in terrorism is associated strongly with the same factors that have made it comparatively less popular as a means of terroristic destruction; the lower level of commitment required, the easier availability of the means to commit arson, and the less impressive nature of even high-profile arsons. The result has historically been that the use of arson in terrorism is not very different from apolitical arsons: sporadic, heavily motivated by cultural factors, relatively low-casualty, and difficult to detect and prevent.

With respect to calculated terrorism rather than opportunistic terrorism, the contrast between arson and other forms of terrorism is revealing. Two conclusions can be drawn from this contrast. The first is that arson is not likely to become a method employed by "serious" terrorists, and that planning to protect buildings from the efforts of determined and sophisticated arsonists may be a waste of time. The second is that arson, when chosen as a method for terroristic violence, is chosen based on non-rational social factors, factors that may in time come to favor the use of arson for calculated acts of terror, as well as opportunistic ones. This latter interpretation is more plausible for several reasons. First, even when arson is used for opportunistic terror, it is associated

[58] Jeffrey White, "The Combat Performance of Hamas in the Gaza War of 2014," *CTC Sentinel* 7, no. 9 (2014), http://www.washingtoninstitute.org/uploads/Documents/opeds/White20140929-CTCSentinel.pdf.

with the general rate of arson in the surrounding area.[59] This tendency suggests that social factors beyond just the ease of carrying out arson make it more popular among relatively low-commitment and disorganized terrorists and more popular in some areas than others. Second, whether Palestinian wildfire arsons are classified as terrorism or military action, such arsons will likely serve as an example to other terrorists, at least Islamic terrorists, and provide a reason to believe that some terrorist groups will at least consider the use of arson in a calculated attack.

What the author concludes about the historical patterns of pyro-terrorism, therefore, is that it has thus far not developed into the distinct category of terrorism that some commentators believe it will likely be.[60] Rather, arson has been one of many tools employed by terrorists, generally in arsons of opportunity rather than as the means chosen to carry out a carefully planned attack. However, the reasons for the comparatively low use of arson in calculated attacks do not suggest that its use will continue to be neglected by terrorists. Arson may be comparatively less emotionally impactful than the use of explosives, for example. It also may enable individual terrorists or terrorist cells to carry out multiple attacks before being neutralized, which makes them perhaps more damaging than had explosives been used.

3. Emerging Concerns

This section examines two new concerns that have not been thoroughly addressed in the literature. The first of these concerns is the use of pyro-terrorism not just as one of many ways by which a terrorist attack can be carried out but rather as a distinctive kind of terrorism. Arson enables the kinds of attacks not possible using other methods, and these kinds of attacks are not adequately protected against by countermeasures targeted at conventional terrorism. The literature has thus far concentrated on the potential use of

[59] Bartkowski, Howell, and Lai, "Spatial Variations in Church Burnings: The Social Ecology of Victimized Communities in the South."

[60] Baird, "Pyro-Terrorism—The Threat of Arson-Induced Forest Fires as a Future Terrorist Weapon of Mass Destruction"; Robert A. Neale, "Performance-Based Design for Arson Threats: Policy Analysis of the Physical Security for Federal Facilities Standard" (master's thesis, Naval Postgraduate School, 2013), http://calhoun.nps.edu/handle/10945/37683; Nick Deshpande, "Pyro-Terrorism: Recent Cases and the Potential for Proliferation," *Studies in Conflict and Terrorism* 32, no. 1 (January 23, 2009): 36–44.

arson as a means of causing forest fires, but other possibilities exist. The second emerging concern is the targeting of first responders by terrorists. The literature on this topic has primarily focused on the use of explosives in terrorism; however, as this section shows, once the probability of a rise in pyro-terrorism is acknowledged, the concerns raised about the targeting of first responders with explosives must be extended to pyro-terrorism.

a. Pyro-Terrorism as a Distinctive Category of Attack

The literature on pyro-terrorism has thus far been concerned with the possibility of using wildfires as a weapon. However, the broader point underlying fears of pyro-terrorism and forest fires has not yet been appreciated. The threat of "forest jihad" is real, but it is not the only threat posed by terroristic arson.[61] Equally concerning—and perhaps more likely to be realized—is the possibility that terrorists will take note of the serious vulnerabilities that certain high-profile urban targets have to fire and exploit those vulnerabilities. Many hypothetical scenarios present themselves, any of which is at least as plausible as the possibility of terrorists using forest fires as a weapon.

Consider one plausible hypothetical example of how a terrorist attack may take advantage of the unique characteristics of arson, as compared to other forms of attack, to reduce the risk to the individual terrorists and potentially even increase the casualty count above what can be produced using explosives or biological agents. Imagine an arson attack on a high-rise building that begins with a fire in a location where fires may occur without antagonistic action. Such locations include kitchens, breaker rooms, and essentially any high-traffic area. In a very tall building, evacuation is generally understood to be impossible, so such buildings are intended to "burn out" rather than be contained or extinguished. Consequently, emergency response in such a scenario would be predicated on the assumption that the fire would ultimately burn itself out, and that it was not necessary to mount rescue operations.

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[61] Jonathan Fighel, "The 'Forest Jihad,'" *Studies in Conflict and Terrorism* 32, no. 9 (September 4, 2009): 802–810.

Strategically placed accelerants or delayed-action fire-bombs, though, could prevent burnout from occurring quickly enough to prevent partial or total collapse of the high-rise. Even worse, the existence of those accelerants would not become obvious until they began to take effect. Occupants and responders who had been acting under the assumption that the fire would burn itself out—an assumption developed based on models of accidental fires rather than intentionally set fires designed to cause mass casualties or structural instability—would be ill-situated to respond to such a development. Consider the likely actions of inhabitants of such a building if they retreated to fire-resistant vestibules, consistent with standard procedure in buildings where evacuation is difficult or impossible.[62] They would have no way of knowing that the fire had continued for longer than was expected, and would likely not perceive the need to change strategies and seek to evacuate. Moreover, by retreating to a fire-resistant vestibule, they might actually have put themselves in a position that would prevent later evacuation without assistance. In such a scenario, the likelihood of mass casualties is very high.

b. Terrorist Attacks Targeting First Responders

When attacks that cause significant damage also greatly harm the organizations responsible for responding to such attacks, they greatly enhance their effectiveness at creating fear and reduce the ability of the local government to respond to those attacks and future attacks. These attacks may actually be even more effective at causing paralyzing fear within first responder organizations than within the general population.[63] First responder psychological recovery is a key question both because first responders are likely to suffer exceptional psychological trauma in responding to a mass casualty event and because when first responders are impaired, they become less able to mitigate the harms of future attacks.

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[62] Chung-Hwei Su, Kuang-Chung Tsai, and Mu-Yuan Xu, "Computational Analysis on the Performance of Smoke Exhaust Systems in Small Vestibules of High-Rise Buildings," *Journal of Building Performance Simulation* 8, no. 4 (July 4, 2015): 239–252.

[63] Sara Garrido and John Nicoletti, "First Responder Psychological Recovery Following a Mass Casualty Event," in *Police Psychology and Its Growing Impact on Modern Law Enforcement*, ed. Cary L. Mitchell and Edrick H. Dorian (Hershey, PA: IGI Global, 2017), 143–157.

The targeting of first responders by terrorists has therefore been a topic of some concern. In suicide bombings and other similar attacks, a "second wave" of bombs is often timed to target first responders.[64] A bomb is detonated in some populated area, perhaps a shopping mall or a crowded intersection. Other bombs are set in the surrounding area and timed to detonate at an interval sufficient to ensure that medical and law enforcement personnel are on the scene providing care and restoring order. These second-wave bombs, although generally causing fewer casualties due to the reduction in victim density in the area, do cause harm that is of very high strategic value. In addition to the "ordinary" psychological trauma associated with responding to a mass casualty event, first-responders targeted by such attacks also must cope with the anxiety of believing they themselves may be under attack while responding. Moreover, they must additionally cope with the loss of their comrades who have been injured or killed by terrorist attacks targeting first responders.

The psychological effects of such attacks can be divided into at least three kinds. The first is the general psychological trauma discussed previously, which may contribute to lower first responder effectiveness and otherwise generally serve the goal of terrorists to cause as much fear and anxiety as possible. The second is the fear and anxiety induced that focuses on responding to terrorist attacks. Such fear and anxiety seems likely to reduce the effectiveness of first responders in responding to such attacks, which allows terrorists to inflict greater casualties because of the reduced effectiveness of the medical response. The third is the inefficiency introduced into emergency response procedures as a result of the necessity of avoiding exposure to second-wave attacks. By way of example, rescue and treatment of the wounded may not be able to progress until law enforcement has arrived and secured the area. In this way, even where a terrorist has not planned a second-wave attack, the possibility of such an attack enhances the effectiveness of the first explosion.

Perhaps because of the enormous proliferation of terrorism in the Middle East, and because that terrorism so often involves explosives rather than arson, much of the

[64] Kong Pin G. Foo, "Exploring First Responder Tactics in a Terrorist Chemical Attack" (master's thesis, Naval Postgraduate School, 2008), http://www.dtic.mil/docs/citations/ADA494195.

literature concerning attacks targeting first responders has focused on bombings.[65] However, there is no reason to believe that terrorist attacks using arson may not target first responders as well. By way of example, imagine a hypothetical case intended to lure first responders into a conflagration on an elevated floor that they could not easily retreat from and could not fight effectively.

The sophisticated terrorist would sabotage the elevators and water distribution system within a high-rise building to prevent easy entrance and exit and also ensure that efforts to fight a fire once on-scene met with failure. In such a scenario, a firefighter team would likely be forced to climb the stairs to the fire rather than wait for the elevators to be fixed, and fatigue would diminish their ability to protect themselves and act rationally once confronted by the fire. The difficulty of establishing water flow when the in-building system has been sabotaged would potentially leave the firefighters, once on-scene, without water for a significant period of time and force them to either retreat back down the stairs or else expose themselves to dangerous heat. Exacerbating the risks such a scenario poses is the plausibility of a partial or total collapse of the high-rise in such a scenario.

[65] Dean T. Olson, *Tactical Counterterrorism: The Law Enforcement Manual of Terrorism Prevention* (Springfield, IL: Charles C Thomas Publisher, 2012), 147.

III. CODES AND REGULATION MITIGATION

This chapter examines the potential of building safety codes to mitigate the risks posed by pyro-terrorism. It begins by discussing the principles of fire safety codes and their two main categories. It then discusses the historical development of those codes with particular emphasis on both the evidence supporting their necessity and on their weaknesses. After this discussion, it proceeds to examine the issues that an ideally designed building safety code addresses in the interests of preventing vulnerability to pyro-terrorism.

The worst-case scenario in any high-rise fire is if that fire leads to a failure of structural integrity, which is true both in economic and in human safety terms. Economically, a complete failure of structural integrity leaves the property owner with an enormous amount of work to do to restore the building; generally, it must be rebuilt from the ground up, and any support structures left standing need to be demolished and removed, with new supports installed. In terms of life safety, which is the focus of the present analysis, collapse jeopardizes those who are ordinarily safe from fire and smoke damage alone. Individuals, who have retreated into fireproof vestibules, although not harmed by the fire itself, will not likely survive the collapse of their building. Firefighters on the scene, although they are insulated from the high temperatures of the fire, have no special protection to allow them to survive a collapse. Furthermore, collapse spreads the danger beyond the building itself. Debris may be scattered beyond the footprint of the building, posing a hazard to anyone it may collide with and making the ground surrounding the building dangerous to navigate.[66] Particulate matter, for instance crumbling concrete, may also contribute to long-term adverse health consequences in the

[66] Robyn R. M. Gershon et al., "Factors Associated with High-Rise Evacuation: Qualitative Results from the World Trade Center Evacuation Study," *Prehospital and Disaster Medicine* 22, no. 3 (May 2007): 165–173.

surrounding area, to say nothing of the potential harms if the building still uses asbestos insulation.[67]

A major concern in preserving structural integrity in high-rises is preventing a localized collapse from turning into a progressive collapse.[68] Local collapses are very difficult to guard against. Even in buildings in which a fire of any realistic intensity is expected to burn out quickly, single sides of the building, or small groups of rooms, may be exposed to heat extreme enough to cause a local collapse. Even though so-called "long-cool" fires present the greatest potential for catastrophic failure in high-rise buildings,[69] a short fire of sufficient intensity may also produce a structural failure. It seems likely that design strategies that presume the inevitability of local collapse are superior.[70]

Accepting the nigh-impossibility of completely preventing local collapse, the challenge for the engineer is to prevent a local collapse from developing into a complete collapse. It is not difficult to see how such a disaster can occur. Consider the case of a 30-floor building that experiences a local failure; the collapse of the westward portion of its 27th and 28th floors. Such a collapse may easily develop into a more serious local or complete collapse in a number of ways. First, the westward portion of floor 26 (and presumably lower floors as well) may collapse under the additional weight of floors 27 and 28 once they are no longer anchored to their support structure. Assuming this collapse does not occur, floors 26 and below may collapse anyway if the westward portions of floors 29 and 30, unsupported from below, fall onto the collapsed portion. Collapse may occur in other ways as well—for instance, the eastward portions of the top

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[67] Samuel Dorevitch et al., "Demolition of High-Rise Public Housing Increases Particulate Matter Air Pollution in Communities of High-Risk Asthmatics," *Journal of the Air & Waste Management Association* 56, no. 7 (July 2006): 1022–1032.

[68] Valerii Pershakov et al., "Progressive Collapse of High-Rise Buildings from Fire," *MATEC Web of Conferences* 73 (2016): 01001; David Scott, Barbara Lane, and Craig Gibbons, "Fire Induced Progressive Collapse," in *Proceedings of the Workshop on Prevention of Progressive Collapse* (Washington, DC: National Institute of Building Sciences, 2002), 10–12.

[69] Susan Lamont, Barbara Lane, and Asif Usmani, "The Behaviour of Multi-Storey Composite Steel Framed Structures in Response to Compartment Fires," *Fire Safety Science* 8 (2005): 184.

[70] Uwe Starossek, "Progressive Collapse of Structures: Nomenclature and Procedures," *Structural Engineering International* 16, no. 2 (May 1, 2006): 113–117.

floors may collapse eastward once the westward portions of those floors no longer balance the floor—but this hypothesis is intended solely to underscore the point that a local collapse (which is not possible to guard against perfectly) can easily develop into a more serious one. A key regulatory requirement, therefore, is redundancy and robustness such that local failures caused by heat will not spread throughout the building.

Statistical analyses of past arsons suggest that arson fires are significantly more damaging than ordinary fires.[71] Where arson and especially pyro-terrorism are deemed especially likely, greater fire resistance is necessary. Conversely, if pyro-terrorism is not likely, the additional structural resilience and fire resistance that this chapter suggests is necessary is prohibitively expensive and is consequently not desirable. In light of the importance of allocating resources efficiently, and not for maximum safety, the need for pyro-terrorism risk assessments like those described in the previous chapter becomes clear.

A. BUILDING SAFETY CODES

Building safety codes are prescriptive or performance-based codes for the construction of new buildings. They can apply to all types of construction or to specific types (e.g., often, specific requirements apply especially to tall buildings, but not to all buildings).[72] Prescriptive codes, which are the earlier of the two kinds of building safety codes, are codes that focus on specific regulations assumed to be the best way to accomplish the goal in furtherance of which the code was established. By way of example, suppose that a code is intended to reduce the vulnerability of buildings to earthquakes. Those responsible for developing a prescriptive code determine, based on their experience or on tests funded specifically for the purpose of code development, how best (or most efficiently) to mitigate the risk of earthquake damage to buildings. They

[71] Martin Nilsson et al., "Analysis of Fire Scenarios in order to Ascertain an Acceptable Safety Level in Multi-Functional Buildings," in *Proceedings of the 9th International Conference on Performance-Based Codes and Fire Safety Design Methods, Hong Kong, China* (Lund, Sweden: Lund University, 2012), 20–22.

[72] George V. Hadjisophocleous, Noureddine Benichou, and Amal S. Tamim, "Literature Review of Performance-Based Fire Codes and Design Environment," *Journal of Fire Protection Engineering* 9, no. 1 (February 1, 1998): 12–40.

then draft a code requiring all buildings constructed under the code to adopt the prescribed method of construction (or, more often, one of a range of acceptable methods of construction). They might say, for instance, that any building over a certain height must either have a pendulum damper or else adopt a tiered design preventing the building's center of gravity from ever traveling over the footprint of its base.

Performance-based codes are those that do not prescribe specific methods, but do set out goals that all buildings constructed under the code must achieve. Compliance of a particular design with the performance requirements of a code is generally assessed by computer modelling, but not always. The compliance of particular materials with performance requirements can often be assessed through experimentation rather than modelling; in many cases, moreover, a particular design for an entire structure must be tested (either at a small scale or full scale) to satisfy the requirements of the performance-based code. Continuing the example of an earthquake safety code, such a performance-based code may require that the building be capable of withstanding an earthquake of magnitude 7 with epicenter 500 yards from the building's foundation. How this performance goal was accomplished, perhaps using a pendulum or hydraulic shock absorbers or space-age materials, is at the discretion of the designer.

As a practical matter, building codes are increasingly adopting a hybrid approach.[73] A blended prescriptive-performance approach minimizes the risk that some innovative building design will be adopted based on an incorrect performance model, but also allows designers and engineers flexibility in using new materials or new designs to mitigate risks more effectively or efficiently than previously possible.

a. The Evolution of Safety Codes

Perhaps, the first Western fire safety code was established in 1666, in response to the Great London Fire.[74] King Charles declared that "no man whatsoever shal presume to

[73] Hadjisophocleous, Benichou, and Tamim, "Literature Review of Performance-Based Fire Codes and Design Environment."

[74] Graham Spinardi, Luke Bisby, and Jose Torero, "A Review of Sociological Issues in Fire Safety Regulation," *Fire Technology* 53, no. 3 (2017): 1011–1037, http://link.springer.com/article/10.1007/s10694-016-0615-1.

erect any House or Building, great or small, but of Brick or Stone, and if any man shal do the contrary, the next Magistrate shal forthwith cause it to be pulled down," and that "all other eminent and notorious Streets, shal be of such a breadth, as may with Gods blessing prevent the mischief that one side may suffer if the other be on fire."[75] Fascinatingly, this code is a hybrid prescriptive-performance code. It mandates a particular material for the construction of all buildings under the code, but does not mandate a particular street width, saying instead that they must be wide enough to prevent the spread of fire. A street lined with carpenters' workshops and sawmills would (at least if such considerations were taken into account by the magistrates) therefore need to be wider than one lined with breweries and stonecutters. It is beyond the scope of this section to consider how this code was actually applied, but the flexibility of the prescriptive approach is important to note.

Another point to take from the early English fire safety code is that the implementation of safety codes generally follows the demonstration of a serious vulnerability, whether that demonstration takes the form of scholarly analysis or actual disaster. In countries among the first to industrialize, disaster has usually been the precipitating factor leading to the implementation of safety codes.[76] The Triangle Shirtwaist fire, which occurred in New York City in 1911, is an obvious case. In the Triangle Shirtwaist factory, exits were blocked during working hours to prevent workers from stealing some of the shirts that they produced (which was apparently a serious concern at the time, and not an uncommon occurrence). As a result, when the factory caught fire, the workers in the factory were unable to escape. More than a hundred workers died, and the political reaction was swift. Commercial buildings were soon required to have a sufficient number of accessible and always unlocked exits to be used in case of fire.

A more recent example is that of China, which has industrialized at a speed far outstripping the speed of any Western nation. This rapid development has created severe

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[75] Spinardi, Bisby, and Torero, "A Review of Sociological Issues in Fire Safety Regulation," 1017.

[76] Richard W. Bukowski and Erica D. Kuligowski, "The Basis for Egress Provisions in U.S. Building Codes," in *Proceedings of InterFlam* (Gaithersburg, MD: Fire Research Division, National Institute of Standards and Technology, 2004), http://fire.nist.gov/bfrlpubs/fire04/PDF/f04031.pdf.

systemic vulnerabilities. For instance, because of the enormous population density in major Chinese cities, extremely large and high-traffic buildings are the norm in China. Consequently, a risk has been acknowledged of catastrophic fire in large commercial complexes, and robust fire codes, which prescribe methods for assessing the fire risk a structure poses, the maximum fire load that a structure can permissibly pose, and required methods of evacuation (among other factors) have been developed to prevent those vulnerabilities from leading to disaster.[77]

b. The Need for Safety Codes

From an economics perspective, it can be unprofitable for a building owner to pursue the greatest possible level of life safety in his building design.[78] Computer modelling has revealed a strong disincentive on the part of building owners to build safer structures than the minimum required. In isolation, it may potentially be tolerated, as individuals with a higher risk tolerance may choose to live and work in less safe, but less expensive, buildings. However, the risks posed by buildings burning out of control are the paradigmatic example of an externality; something that is not "priced in" for the person making a given decision.[79] A burning building imposes severe negative externalities on both the city in which the building is located (which must provide fire services, but generally does not tax based on a building's level of fire-resistance), and especially adjacent buildings, which have no say in whether they are exposed to flames pouring from the windows of the building next door. Since the costs of unsafe structures are not fully borne by the party selecting the design for a structure, an economic analysis of the question suggests that the state should intervene either by taxing unsafe structures or by outlawing them.[80]

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[77] M. A. Qian-li and Huang Ting-lin, "Analysis of and Study on the Difficulties in the Fire Protection Design of Large Commercial Complex," *Procedia Engineering* 11 (January 1, 2011): 302–307.

[78] S. Khajehpour and D. E. Grierson, "Profitability versus Safety of High-Rise Office Buildings," *Structural and Multidisciplinary Optimization* 25, no. 4 (October 1, 2003): 279–293.

[79] Yew-Kwang Ng, "Externality," in *Welfare Economics*, ed. Yew-Kwang Ng (London: Palgrave Macmillan UK, 2004), 144–163.

[80] This situation happens because externalities, definitionally, are not accounted for by market pressures, and therefore, must be accounted for in some other way.

More generally, structural analysis of various administrative agencies and their interactions with building designers has revealed that so-called "disconnected actors" can be disastrous for efficiently allocating resources towards fire mitigation and prevention.[81] The problem of effective decision making with respect to fire safety is so complicated that not only is it difficult for individual building owners to make safe decisions, even where they are motivated to do so; governmental agencies themselves also experience difficulty evaluating and weighing risks.

From a sociological perspective, fire safety regulation prevents safety from being beholden solely to the profit motive, democratizing fire safety, and giving even those with little economic power a say in their own security.[82] That is, fire safety codes and similar regulations have historically corresponded to the interests of politically powerful groups. Of course, some very poor individuals cannot afford any housing at all but may be able to do so if safety codes did not drive up the cost of that housing.[83] It is tempting to suggest that fire safety codes should prioritize protection over price, but one of the key insights that a sociological investigation of such codes holds is that to make that decision can further disempower the poor.

B. PRESCRIPTIVE AND PERFORMANCE-BASED CODES

The necessity for fire safety codes has long been acknowledged and has more recently been shown rigorously. Until recently, however, modern building safety codes were almost entirely prescriptive rather than performance-based.[84] These codes generally did not have the effect of preventing fires. In fact, they may actually have increased the

[81] Kalliopi Sapountzaki et al., "Disconnected Policies and Actors and the Missing Role of Spatial Planning throughout the Risk Management Cycle," *Natural Hazards* 59, no. 3 (December 1, 2011): 1445–1474.

[82] Spinardi, Bisby, and Torero, "A Review of Sociological Issues in Fire Safety Regulation."

[83] This situation occurs because any marginal increase on price, in a large market, will inevitably put the product beyond the reach of some individuals who could, before the change, just barely afford the product.

[84] Hadjisophocleous, Benichou, and Tamim, "Literature Review of Performance-Based Fire Codes and Design Environment."

risk of fire relative to simply allowing building owners to accept whatever risk level they preferred, as prescriptive codes were not only expensive but also at times out of date.[85]

Hadjisophocleous, Benichou, and Tamim also present several challenges *on principle* to prescriptive codes.[86] First, prescriptive codes rely on requirements rather than on objectives, which is problematic because requirements are only an indirect and imperfect way of accomplishing the desired outcome (increasing fire safety).[87] By presenting a rigid set of building requirements, and not providing some flexibility to ensure that those objectives are met, prescriptive codes pose the double risk of not accomplishing those objectives in some cases, and being inefficient in others.[88] Imagine that Louisiana adopted a building safety code with the goal of mitigating the dangers posed by storm surges. Such a code would be highly applicable to some buildings (those within the potential area covered by a storm surge), but would be entirely unnecessary for others. If such a code specified construction methods (e.g., building on stilts), then many buildings would be exposed to greater costs without justification. If, however, a performance-based measure was adopted (e.g., that the building must be elevated to at least two feet above the area's highest recorded storm surge), then only those buildings that needed to be built differently would be affected by the code—a more efficient outcome.

Second, prescriptive codes have historically not considered cost adequately in large part because of the previous criticism.[89] As prescriptive codes are outcome-blind, they generally do not make exceptions for protection that is *almost* as good and far

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[85] Hadjisophocleous, Benichou, and Tamim, "Literature Review of Performance-Based Fire Codes and Design Environment," 13.

[86] Ibid.

[87] Indirect and imperfect as compared to managing the level of fire safety directly in a particular building and deciding whether that level of safety is adequate.

[88] James Lord and Chris Marrion, "Developments in Codes around the World," *Fire Protection Engineering*, accessed August 13, 2017, http://www.sfpe.org/page/2003_Q3_2.

[89] Hadjisophocleous, Benichou, and Tamim, "Literature Review of Performance-Based Fire Codes and Design Environment."

cheaper (nor, actually, do they make exceptions for both better and cheaper protection).[90] Even in situations in which a particular prescribed method is unreasonably expensive, that method still needs to be applied because exceptions are generally not permitted under prescriptive codes.

Third and finally, prescriptive codes stifle innovation.[91] This aspect of prescriptive codes is perhaps the most unfortunate in the long term. The justification for prescriptive codes in the face of ongoing innovation that makes those codes obsolete is that they are updated once new technologies mature and are shown to have the claimed advantages over more established designs. However, prescriptive codes greatly reduce the incentive to take part in the development of innovative designs and technologies, because those technologies cannot be implemented in the areas covered by prescriptive codes.[92]

Purely prescriptive codes do have one significant advantage, however; methods for estimating the performance of developing fire-safety technologies can prove inaccurate.[93] The only perfectly accurate way of determining a building's resistance to fire is actually to set it alight. By way of example, imagine a sprinkler head that is able to distribute more water, and with greater regularity in patterns of distribution, than previous designs. Suppose that this sprinkler head has a tendency to malfunction in extremely humid environments, but all testing is conducted in Arizona or some other dry area. It only becomes apparent in actual practice that this sprinkler design does not live up to its theoretical performance. In this way, innovation—even careful innovation—can at times create riskier structures than intended.

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[90] By way of example, consider the case of the fire at Grenfell Tower, in which a slightly cheaper form of cladding was used in the tower's construction. "What Happened at Grenfell Tower?," BBC News, July 19, 2017, sec. London, http://www.bbc.com/news/uk-england-london-40272168.

[91] Ibid.

[92] Ibid.

[93] Hossein Mostafaei, "Hybrid Fire Testing for Assessing Performance of Structures in Fire—Application," *Fire Safety Journal* 56 (February 1, 2013): 30–38.

C. HYBRID FIRE SAFETY CODES

This section of the chapter discusses key considerations for regulatory mitigation of the risk of pyro-terrorism and also examines the methodological shift in regulatory approaches to fire safety. This shift, which is critical to understanding what regulations can do to mitigate the risk of pyro-terrorism, is discussed in the first sub-section. Some of the key concerns that arise in evaluating the level of safety to fire damage that a given high-rise structure has are discussed next. The main concerns discussed in this thesis are the preservation of structural integrity in the face of fire, the effectiveness of automatic mitigation systems, and the feasibility of independent or firefighter-assisted evacuation. The next sub-section examines sustainability concerns, and the review then turns to the special challenges of regulatory mitigation of pyro-terrorism, as distinct from ordinary fire.

A hybrid code contains elements of both prescriptive and performance-based codes; for instance, it may say that support structures may be composed of a particular sort of steel column; but if they are not composed of that sort of column, they must demonstrate a particular level of stability and heat resistance. Such a code encourages innovation while at the same time ensuring that performance does not fall below a minimum standard. Due to the availability of a specific, pre-approved construction method, the performance standards for other methods can be higher than they strictly need to be, reducing the likelihood that an error in predicting performance can result in disaster. Based on the sensitivity of developers to profitability and the minimization of costs, the author argues that even when safety requirements are raised for non-standard approaches, innovation is still encouraged by the possibility that a new method may prove cheaper than established technologies and designs.

A concern that applies not just to prescriptive codes but also to performance-based codes is the preservation of transparency and the elimination of so-called "magic numbers."[94] Magic numbers are elements of a regulation the source of which is not made

[94] Emanuele Gissi, Enrico Ronchi, and David A. Purser, "Transparency vs Magic Numbers: The Development of Stair Design Requirements in the Italian Fire Safety Code," *Fire Safety Journal* 91 (July 1, 2017): 882–891.

clear in the regulation or its supplemental materials. These numbers generally "were developed according to the best information available at the time, sometimes informed by experimental studies, often involving some degree of experience or engineering judgment, or in some cases simply to standardize products (such as door sizes)."[95] An example of the applicability of this concept to performance-based fire safety codes is as follows. Many safety codes prescribe a certain interval of fire resistance (commonly 60 or 90 minutes) that is generally chosen to allow for complete evacuation of the building. Over time, however, evacuation methods will likely become more effective and the amount of time necessary for complete evacuation will likely decrease. To encourage responsiveness in regulatory codes to these developments, the method by which the "magic number" representing fire resistance time was selected should be made transparent.

Even within performance-based codes, great variation occurs as to how performance is assessed. The so-called "prescriptive" method (which is referred to as the traditional method) is that a particular construction material or design must be tested using physical testing, and the more modern method allows for the use of computer simulation.[96] Thus, a hybrid approach has been suggested, in which the component being tested is exposed to a physical test, while in parallel a building constructed using that component is simulated using computer modelling, adjusting its simulation to account for any unexpected results from the physical test. This approach has several advantages. First, the costs of computer modelling are far less significant than the costs of physical testing, so the traditional approach does not significantly raise costs.[97] Second, by simulating the performance of the entire structure rather than just evaluating the component's adherence to rigid, parametric performance standards, the hybrid method of evaluation allows for the assumptions of the regulation (e.g., that a particular kind of deformation does not lead to collapse) to be checked. Third, because the required

[95] Gissi, Ronchi, and Purser, "Transparency vs Magic Numbers: The Development of Stair Design Requirements in the Italian Fire Safety Code," 882.

[96] Mostafaei, "Hybrid Fire Testing for Assessing Performance of Structures in Fire—Application," 30–38.

[97] Ibid.

physical tests are still conducted, the hybrid method of evaluation will not lead to less accurate results than the traditional method of evaluation. Fourth and finally, because physical tests are conducted, the accuracy of computer modelling is enhanced; just as the use of computer models allows the tester to check the assumptions of regulators, so too does the use of physical testing that allows the testers to check the assumptions of their computer model.[98]

1. Effectiveness of Mitigation and Evacuation

A major concern is that fire mitigation systems and materials often do not practically live up to their theoretical effectiveness.[99] One example is fire-retardant insulation.[100] Polystyrene insulated panels are a commonly used construction material. They consist of a polystyrene core attached to a thin metal skin, which retains the panel and provides structure. These panels are highly effective and cost-effective insulators, and are consequently used in many structures. They also are theoretically fire-resistant and are generally considered not to add significantly to the energy available to a fire. However, these theoretical conclusions are dependent on a number of assumptions that may not hold up in practice; for instance, on the ability of the fasteners of the panels to remain attached even when exposed to heat. When the panels fall into a fire, and especially when the metal skin of the panels is broken, they contribute to the fire's growth rather than inhibit it.

Incidentally, the vulnerability of these insulated panels is a fantastic example of the concerns raised earlier Sabotage may inhibit the effectiveness of fire mitigation systems, which allows a sophisticated arsonist or pyro-terrorist to inflict greater harm than projections suggest. Since the metal skin of these insulated panels is so thin, it can

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[98] Mostafaei, "Hybrid Fire Testing for Assessing Performance of Structures in Fire—Application," 30–38.

[99] P. C. R. Collier and G. B. Baker, "The Influence of Construction Detailing on the Fire Performance of Polystyrene Insulated Panels," *Fire Technology* 49, no. 2 (April 1, 2013): 195–211; Pershakov et al., "Progressive Collapse of High-Rise Buildings from Fire."

[100] Collier and Baker, "The Influence of Construction Detailing on the Fire Performance of Polystyrene Insulated Panels."

be damaged inadvertently or (more worryingly) deliberately, and this damage can be done unobtrusively and by someone with only brief access to the panels in question.

Fire safety protocols that do not ensure the ability of inhabitants to protect themselves are suspect. When automatic measures fail—and they often do—individual action to evacuate or otherwise protect oneself is a measure of last resort.[101] One critique of measures of evacuation safety (like the required safe egress time) is that especially in high-rise buildings, an individual agency is not taken seriously, which leads to measures that do not truly show whether a building is evacuable.[102] Babrauskas et al. argue that the metric commonly used to ensure that a building can be safely evacuated, the ratio of required safe egress time to available safe egress time (or RSET/ASET) does not consider how individuals actually behave when evacuated from buildings in the case of fire or similar disasters. RSET is calculated under the assumption that evacuees will proceed robotically to the nearest exit upon receiving the instruction to evacuate. This inaccurate assumption can be especially dangerous where unexpected circumstances (for instance, a greater fire intensity than projected that can caused by a terrorist attack) reduce the ASET by accelerating the spread of fire or the collapse of the structure.[103]

More generally, the fire-fighting task can in many contexts become impossible in tall buildings because of the difficulty of reaching the fire and evacuating inhabitants.[104] Individuals on the 40th floor of a burning building, for instance, cannot rely on firefighter rescue, nor can firefighters count on being able to reach the top floors of such a tall building in time to prevent its destruction.[105] Such buildings rely on burnout—the process by which the fire extinguishes itself as it encounters fuel that does not produce enough heat to sustain the fire—rather than on active fire-fighting measures. However,

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[101] Pershakov et al., "Progressive Collapse of High-Rise Buildings from Fire," 2.

[102] Vytenis Babrauskas, Joseph M. Fleming, and B. Don Russell, "RSET/ASET, A Flawed Concept for Fire Safety Assessment," *Fire and Materials* 34, no. 7 (November 1, 2010): 341–355.

[103] Ibid.

[104] Birgit Östman and Daniel Brandon, "Fire Safety Engineering--Opportunities and Challenges for Timber Buildings," in *World Conference on Timber Engineering WCTE2016, Vienna, Austria, August 22–25 2016* (Uppsala, Sweden: Digitala Vetenskapliga Arkivet, 2016), http://www.diva-portal.org/smash/get/diva2:1014997/FULLTEXT01.pdf.

[105] Ibid.

the safety of this decision is questionable in light of the material addressed previously about the potential failures of fire mitigation systems. The determination that a fire will burn itself out is made based on the availability of fuel. If the fuel availability is below the amount the fire needs to sustain itself, the fire will inevitably burn out. However, the fuel availability calculations that these determinations rely on may themselves be inaccurate, as the previous discussion of insulated panels shows.

2. Sustainability and Fire Mitigation

One example of a trend in high-rise construction with the potential to make high-rises more safe or less safe, depending on how it is approached, is the use of novel, more sustainable materials. The use of timber for high-rise construction is growing more popular and will likely continue to do so.[106] This usage is obviously a cause for some concern, as wood is known for being a very combustible construction material. However, it is not necessarily the case that timber construction of high-rise buildings will make those buildings less fire-resistant.

In the case of timber supports for high-rises, a useful analogy can be drawn concerning the aforementioned insulated panels discussed previously. For high-rise buildings, partial or complete encapsulation of combustible building elements has long been recommended.[107] The goal of encapsulation is to prevent any combustible elements from being exposed to oxygen and heat, which allows them to burn and contribute to the fire's spread. In the case of insulated panels, this encapsulation takes the form of a very thin metal lamination. Recent research suggests that some laminated timber supports may be self-encapsulating, and that heavy timber frames may be sufficiently fire-resistant to be usable without other encapsulation.[108] Sufficiently thick laminated timber frames, when exposed to fire, will develop a thick layer of char that does not easily flake off the

[106] Yves Martin et al., "Fire Safety of Timber Buildings under Construction—Overview of Guidelines and Recommendations," in *Dissemination, Standardization, and Implementation of Novel Improvements* (presented at the COST FP 1404, ethz Zurich, 2017), 31.

[107] Östman and Brandon, "Fire Safety Engineering--Opportunities and Challenges for Timber Buildings."

[108] David Barber and Robert Gerard, "Summary of the Fire Protection Foundation Report—Fire Safety Challenges of Tall Wood Buildings," *Fire Science Reviews* 4, no. 1 (December 1, 2015): 5.

remaining wood. This layer of char prevents the remaining unburnt timber from being exposed to oxygen; moreover, the char is an excellent insulator that prevents the core of the timber frame from being exposed to sufficient heat to cause warping or a loss of structural integrity.

Such timber frames are disanalogous to insulated panels in a key way; since the timber frames are inherently self-encapsulating, they are not as vulnerable to sabotage as insulated panels and other combustible materials that must be manually encapsulated to prevent them from contributing to building fires. An arsonist seeking to sabotage the previously described insulated panels could puncture the metal laminate covering them. An arsonist seeking to sabotage timber supports does not have the same option. This finding serves as an excellent example of one principle that the author draws from his review of the literature on regulatory mitigation of pyro-terrorism, sabotage resistance. Consideration of a design's ordinary characteristics is insufficient to establish whether it is vulnerable to pyro-terrorism. An adequate analysis considers not just the level of vulnerability under optimal conditions but also the level of vulnerability when the attacker has had some level of prior access to the structure and has been able to sabotage it.

However, timber frames may be vulnerable to arson in another way. When fires of a sufficiently high intensity are set, laminated timber can act to intensify rather than retard its spread.[109] When the laminate that holds layers of timber together fails as a result of high heat, these layers fall apart, which prevents the encapsulation of lower layers and adds to the available fuel. This is not to say, necessarily, that laminated timber is unsuitable for buildings at high risk of arson or pyro-terrorism; rather, it is intended to highlight the importance of considering the worst possible scenarios for a given structure, component, or material to have a complete picture of a building's fire-resistance.

[109] Barber and Gerard, "Summary of the Fire Protection Foundation Report—Fire Safety Challenges of Tall Wood Buildings," 7.

D. SPECIAL CONSIDERATIONS FOR ARSON AND PYRO-TERRORISM

Even more so than when evaluating a structure's resistance to ordinary fires, a key consideration for mitigating the risk of arson, and especially pyro-terrorism, is structural robustness.[110] Due to the extraordinary harms of high-rise collapse discussed previously, a natural goal of pyro-terrorists targeting tall buildings is to induce partial or total collapse. They will often be able to produce the conditions necessary for at least a localized structural failure, so structural redundancy and alternate load pathways are necessary to ensure continued structural integrity. It should not be difficult to understand the reason. A hallmark of intentional, as opposed to accidental, fires is that they occur in circumstances more conducive to major damage. For example, an intentional fire generally involves the use of accelerants intended to increase the heat of the fire, which causes some materials that may ordinarily subtract from the available fuel to instead contribute to the fire.

By way of example, consider the laminated timber discussed earlier, which is in most cases, reasonably fire-retardant. Under ordinary circumstances—that is, when a fire is of an intensity that can reasonably be expected from an accidental fire—laminated timber does not catch fire as supposed. The outer layers of the timber do char but are held to the beam by the lamination, which prevents oxygen from reaching unburnt wood and acting as an insulator. Through the use of accelerants, however, a fire can be set that is hot enough to cause delamination that exposes deeper layers of the timber and causes the timber support to catch fire exactly as can be expected of untreated timber. Similarly, the laminated insulating panels described previously can be sabotaged in one room or one region of a building, which causes them to contribute to the growth of a fire. Since an arsonist is often able to defeat passive countermeasures like lamination, which produced very intense flames, it is impossible to be confident that an arsonist is not able to cause at least a local collapse. What is essential, therefore, is designing structures with sufficient robustness that a local collapse is not likely to progress into a complete collapse.

[110] Ian Bennetts, Lam Pham, and Others, "Structural Robustness and Fire," in *Australasian Structural Engineering Conference: ASEC 2016* (Barton, Australia: Engineers Australia, 2016), 155.

A special question that arises with respect to code mitigation of the threat posed by pyro-terrorism is resource allocation and the identification of likely targets. Some buildings are not likely to be targeted by a pyro-terrorist, any more than they are likely to be targeted for a bombing or a mass shooting. This is not to say that a pyro-terrorism event is unlikely to occur, at, for example, an ordinary apartment complex that is not politically significant, but it is to say rather that if the risk of an attack is deemed so low that it is not worth it to install on-site security personnel or metal detectors to protect against more conventional terrorist attacks, it may not be worth imposing strict building safety requirements to protect against pyro-terrorism.

At least one general consideration with respect to resource allocation and target prioritization presents itself. Multi-function buildings are at an especially high risk for arson, to include pyro-terrorism.[111] Terrorists are generally at best indifferent to collateral damage inflicted—sometimes they prefer collateral damage, and sometimes, they simply do not care whether collateral damage occurs or not, so long as their target is destroyed—which means that a multi-purpose building that houses a target of significance to the terrorist is likely to be no less valuable a target than a single-function building. Exceptions do occur, of course (for instance, the Oklahoma City bomber chose to avoid targets that would have a great number of casualties unaffiliated with the government)[112] but those exceptions are just that, exceptions. Suppose that a very naive analysis of terrorism vulnerability to each structure is applied, which reduces the measure of vulnerability to the question of whether a target is located in the structure that a terrorist likely wants to attack. It should be clear that multi-function buildings come out far worse than single-function buildings in this analysis. The problem however is more significant than that since multi-function buildings are likely to present a wider range of vulnerabilities (as the number of persons admitted to the building is far greater than in a single-person building), expose a wider range of potential victims (which may be relevant

[111] Bennetts, Pham, and Others, "Structural Robustness and Fire," 155.

[112] Lou Michel and Dan Herbeck, *American Terrorist: Timothy McVeigh and the Oklahoma City Bombing*, 2nd. ed. (Pennsauken, NJ: BookBaby, 2015).

in assessing the potential psychological impact of an act of terrorism), and have a greater absolute number of victims.

A related concern also arises of assessing whether special precautions are necessary to protect against pyro-terrorism while a building is under construction, which for several reasons is when they are most vulnerable.[113] First, many of the more critical fire countermeasures (smoke alarms, automatic sprinkler systems, and so on) are not installed, or else are not operational, until a very late stage in the life cycle of a construction project. Second, the lower level of traffic in and around a building under construction makes it less likely that an arsonist is observed and intercepted before a fire can be set. Third, many of the more flammable components of a building are directly exposed while it is under construction. Consider the flammable insulation panels described previously: those ordinarily are hidden behind drywall and generally inaccessible, which prevents an attacker from easily accessing them to damage them. While a structure is under construction, however, those panels are far more likely to be exposed and (consequently) vulnerable.

With that said, it seems unlikely that special steps need to be taken during construction to guard against pyro-terrorism, since many of the factors that have made pyro-terrorism generally less appealing to terrorists apply with even greater force in the case of buildings under construction. First, the destruction of a building that has not yet been completed does not send a strong message of the terrorist group's power, nor is it likely to inflict fear in the minds of many.[114] A person who witnesses the destruction of a completed high-rise might plausibly think, "I could have been in that building;" while a person who witnesses the destruction of an incomplete building likely does think this way. Second, the destruction of an under-construction building is not likely to impose anything like the economic damage that a completed building does. Consider the

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[113] Len Garis et al., *Construction Site Fire Response* (Abbotsford, BC, Canada: University of the Fraser Valley, 2015), http://wood-works.ca/wp-content/uploads/UFV-Research-Construction-Site-Fire-Response-Mar-2015.pdf.

[114] Mikkel Thorup, "Terror as Terror: The Return of Fear and Horror?," *Borderlands* 10, no. 3 (2011), http://go.galegroup.com/ps/i.do?id=GALE%7CA289216313&sid=googleScholar&v=2.1&it=r&linkaccess=fulltext&issn=14470810&p=AONE&sw=w.

destruction of an office complex, which of course is an enormous cost to the insurers of the office building. However, it also is a major cost to the countless businesses whose operations are disrupted by the need to relocate, the possibility of destroyed data or critical materials, and the potential deaths of key employees. By contrast, the destruction of a building that has not yet begun to be used harms only the building's owners, or at least their insurers.

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IV. TACTICAL MITIGATION OF PYRO-TERRORISM

It is largely the special challenges of firefighting in dense cities that has driven innovation and increased focus on training and drill. City fires are larger; they have more places to expand, and more fuel nearby. City fires are also more dangerous and destructive. The populations of cities are greater with more valuable things. Thus, the development of structured fire departments, and then the development of specific training regimens, and the increasing focus on formal education for leadership, has roughly tracked the development of the metropolis (hence, e.g., the earlier development of firefighting professionalism in London than in the United States, where for some time, London could not be rivaled in size, density, or affluence).

Therefore, the increasing challenges posed by high-rise fires as high-rises become ever larger and ever more enticing targets for arsonists are likely to impose special demands on firefighters, who likely must adjust their organization, their technological solutions, and even their tactical approach to firefighting to accommodate these special needs. Historically, the challenges imposed by increasingly dense development have led to the most serious fires—witness, for instance, the Great Fire of Edinburgh—and have made fires more difficult to fight, requiring new technologies and ways of organizing fire response (for instance, it is difficult in the modern era to appreciate fully how great the metropolitan fire risk can be if not for the emergence of constant, nearly omnipresent water access in every building).[115] High-rise buildings, as the culmination of a general trend towards denser buildings (and denser populations inhabiting those buildings), require still more advanced fire-fighting techniques.

A. COMMUNICATION AND COORDINATION

The modern approach to firefighting—especially in urban areas—focuses on communication and coordination.[116] For one thing, firefighting entails a number of

[115] Ewen, *Fighting Fires: Creating the British Fire Service, 1800–1978* (Berlin, Germany: Springer, 2009), 34.

[116] James S. Angle et al., *Firefighting Strategies and Tactics* (Burlington, MA: Jones & Bartlett Publishers, 2013), 86.

distinct but related tasks: the evacuation of persons vulnerable to the fire who cannot evacuate under their own power, coordination between the fire department and other first responders, the provision of immediate lifesaving care before medical personnel arrive, instruction of and response to bystanders and their needs, and of course, extinguishing or at least controlling the fire. This last task itself has numerous divisible components, from entering burning rooms to extinguish from within to supplying water to cool such rooms from outside, to performing support activities like monitoring and maintaining hose connections.[117] The divisibility of the firefighting task thus leads to a heightened emphasis on communications and coordination.

For another thing, the potential risk posed by fires has increased dramatically, as has the magnitude of related problems that firefighters must address. In a word, more materials are available to burn. The increasing density of modern living—in buildings made of a surprising proportion of flammable material—means that a fire of a given size will put many more lives at risk than in earlier years. This increase in the scope of the firefighting task necessitates a greater number of firefighters responding to serious incidents than in the earlier days of the development of firefighting. The adage that too many cooks spoil the broth is not quite true in this case, but the principle it reflects—that confusion and wasted effort multiplies as additional workers join any effort—certainly is. To mitigate this confusion and to ensure that the addition of more firefighters to any given task is efficient, communication is paramount.

Such communication has, of course, developed over time. The first form of on-site communication used by firefighters was in-person communication ("John, go around to the back of the house"), no doubt supplemented with the use of runners to relay information ("Jim, go around to the back of the house and tell John he needs to move south").[118] These methods of firefighter communication are still important today, especially face-to-face communication between persons who are on-site but not inside the building. Sign language may also be used to coordinate while firefighters are wearing

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[117] Gary Bowker, "Firefighting Tactics to Beat 21st Century Fires," *FireRescue1*, July 15, 2012, https://www.firerescue1.com/fire-attack/articles/1315403-Firefighting-tactics-to-beat-21st-century-fires/.

[118] Angle et al., *Firefighting Strategies and Tactics*.

protective gear that prevents their words from being heard. Even so, it should be clear that such solutions are not adequate for modern firefighting. In the modern firefighting context, on-site coordinators are generally not within the building that is on fire (and certainly are not at the site of the burning itself), putting them at an extreme physical remove from those with whom they need to communicate. Moreover, many firefighters need to communicate with the on-site coordinator, and what one firefighter has to say does impact what the coordinator tells another firefighter to do.

Two natural solutions present themselves, both of which have been adopted by modern fire departments, the use of electronic communication to enable instant contact and the use of pre-composed plans so that instant contact is not necessary for the coordinator to know what the firefighters are doing.[119] Each has its own set of weaknesses, of course. Electronic systems can fail, and if they can fail, they are most likely to do so at times of high stress; for instance, when they are exposed to the heat and smoke of a major fire. Particulate matter in the air can be particularly problematic for electronic systems, as can network saturation caused by an unexpectedly large fire necessitating more firefighters than was planned for. Pre-written plans are only as good as the information on which they are based, and no information is perfect. The modern fire department therefore is likely to use a hybrid system in which communication occurs through the aid of electronic systems, but a preliminary plan is established based on the information available to the fire department before the burning structure is ever approached.

Coordination is especially important in fighting high-rise fires. The importance of coordination in fighting high-rise fires is highlighted in the practitioner literature, "there is no room for freelancing at fires, especially in high-rise buildings."[120] Two further reasons are critical for coordination in fighting fires in high-rise buildings. The first is the need to be able to rescue firefighters who are incapacitated, and the second is the possibility that some portions of the building are or will become too dangerous to approach.

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[119] Angle et al., *Firefighting Strategies and Tactics*.

[120] Ibid., 332.

Firefighters in a high rise have firsthand knowledge of only part of the situation. The on-site coordinator, by contrast, receives reports from multiple different teams of firefighters and can observe the situation outside the building. Imagine, to illustrate the importance of effective communication, a multiple-front fire in a high rise being fought on several floors, and the top floor collapses partially. The firefighters on the top floor of course are aware of this collapse, and if the building in question is vulnerable to progressive collapse, they know to evacuate or at least retreat. Firefighters further down, however, are not aware that a collapse has begun, and may be trapped if the collapse continues. For another example, imagine a structure in which two sides of floor 26 (the north and west sides) are engulfed in flame, and one side of floor 27 (the north side) is also burning. It is possible for an outside observer to see flames crawling up from the windows of floor 26, and if they spread to floor 27, the firefighters on that floor are subsequently surrounded by those flames. Thus, the team on that floor is not be able to observe the situation until it was too late, or nearly so—and even if they can, they are probably so distracted to the point of not realizing the danger.

The effectiveness of electronic communication methods for high-rise firefighters is thus of paramount importance. However, firefighter communication technologies are generally weak.[121] Technologies in place to facilitate communication often fail. The reasons are manifold, as discussed previously; heat and suspended particulate matter can interfere with communication effectiveness. Some fire departments may have outdated communication technology that cannot function properly at the distances necessitated by very tall buildings, or that cannot ensure adequate signal strength when separated by 20 floors of insulating material. In extreme cases, also, communications networks can become oversaturated. All these occurrences are problematic even without considering the possibility of intentional efforts to impair communication.[122]

With respect to the research that must be undertaken, then, it is necessary to have a clearer idea, based on sound science, of just how urgent the need to modernize

[121] Markus Scholz et al., "A Concept for Support of Firefighter Frontline Communication," *Future Internet* 5, no. 2 (April 16, 2013): 113–127.

[122] Harry Goldstein, "Radio Contact in High-Rises Can Quit on Firefighters," *IEEE Spectrum* 39, no. 4 (April 2002): 24–27.

firefighter communication is. Such an inquiry ideally consists of three components. The first is to evaluate proposed systems (and systems actually in use by fire departments) for their ability to facilitate communication between multiple firefighter teams simultaneously. In other words, the risk of saturation of available frequencies must be considered. Of particular note is the point that it may be insufficient to have a system that can stand up to the traffic of having all the department's firefighters on the air, because parallel public safety organizations are likely to use similar wireless systems, and in a large-scale attack, are very likely to be deployed to the same location. At a confirmed terrorist attack, for instance, the police or the Department of Homeland Security are almost certain to be on the scene quickly; even when terrorism is a mere possibility, medical personnel are normally on-scene. The second component is to consider the potential effect of particulate matter on the efficacy of the communication system. The third component is to consider the effect of any intentional efforts to jam the communication system. What is important to note is that these situations cannot all be applied separately; it is essential that some sort of understanding as to how frequency saturation may make a communication system more susceptible to accidental or intentional jamming, for instance.

With respect to how this research should be applied in the creation of sound policy, it is difficult to say without knowing in advance what the results of such an investigation can be; it may well be that a technically ideal solution is unfeasibly expensive. At the very least, moreover, decision makers should have the benefit of such an analysis when making purchasing decisions. Perhaps more importantly, first responders should also have this information. The on-site leadership should know, for instance, that at their maximum deployment of five teams, if two teams of medics are also on-site and heavy voice traffic is occurring, then their communications system become excessively vulnerable to intentional jamming or disruption as a result of smoke and suspended particles. Thus, responders are able to plan for this eventuality simply by knowing that the wireless system is at a higher risk of failure.

B. ACCOUNTING FOR AIR MOVEMENT

A critical point in fighting high-rise fires is air movement within the building—that depends on the HVAC system[123]—and air movement from outside the building.[124] With respect to air movement within the building, this movement is relevant both because relatively oxygen-rich air can be fed by natural circulation or the HVAC to the fire, which allows it to grow quickly when it may otherwise have slowed due to a lack of oxygen. Feeding the fire may in fact be a mixed blessing, as it greatly reduces the risk of backdraft, but this advantage is likely not worth the cost of allowing the fire to intensify and spread before the firefighters can arrive on-scene to control it. The HVAC can also circulate smoke to areas that otherwise may have been smoke-free. Allowing smoke to spread throughout the building can make a fire much more difficult to combat because it impairs visibility and requires resources to be devoted away from firefighting and towards the immediate evacuation of all civilians within the building. Although the evacuation of civilians is always a priority, it may be possible to focus manpower on containing a fire rather than on assisting the evacuation if the fire is in only one portion of a building and the evacuees are not at risk of carbon monoxide poisoning or the other harms of smoke inhalation.

C. EVACUATION

Firefighters may find it difficult or impossible to assist with an evacuation in a high-rise because they do not have access to the higher floors. Exterior access by firefighters generally does not exceed seven stories.[125] This situation is not commonly problematic, as the overwhelming majority of high-rise fires are extinguished before firefighter arrival and started below the 7th story, but they can certainly pose challenges

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[123] Angle et al., *Firefighting Strategies and Tactics*, 332.

[124] Prabodh Panindre, N. S. Susan Mousavi, and Sunil Kumar, "Positive Pressure Ventilation for Fighting Wind-Driven High-Rise Fires: Simulation-Based Analysis and Optimization," *Fire Safety Journal* 87 (January 1, 2017): 57–64.

[125] Musab Alamir Musa, "Fire Safety Management System in High-Rise Building" (master's thesis, Sudan University of Science and Technology, 2016), http://repository.sustech.edu/handle/123456789/14958.

when a fire is intentionally set to frustrate firefighter response.[126] Where evacuation is necessary, and firefighters are required to assist with evacuation, the difficulties associated with evacuating people from—say—the 20th floor of a high-rise should be obvious. Not only do firefighters have to travel to these people, transporting a device (invariably bulky) with which to evacuate them, they may also have difficulties locating the people to be evacuated, especially when the building is filled with smoke, which is when the need for evacuation is greatest.

An emerging challenge for firefighters, which may be more significant, is the use of elevators for evacuation.[127] In previous years, elevators have been used only by firefighters in evacuation, because they allow firefighters to reach the fire quickly and without becoming out of breath.[128] They have generally not been necessary for evacuees. For what should be obvious reasons, elevators are generally more beneficial to persons needing to ascend than persons needing to descend. However, the advent of super-high-rise buildings is changing this paradigm.[129] A 100-story building with congested evacuation corridors (that be achieved by an even moderately sophisticated terrorist who, e.g., sabotages a fire staircase with a slippery substance, broken glass, or more significant weapons) takes around two hours to evacuate completely. High-speed elevators of the kind and quantity necessitated by high-rise buildings, by contrast, allows for relatively rapid evacuation, on the order of fractions of an hour. Questions of organization of evacuees to promote the efficient use of elevators are beyond the scope of this thesis; what is important to keep in mind is that the use of elevators for fire evacuation, which was formerly verboten, may in fact be necessary today.

Although promising from a perspective concerned primarily with life safety in high-rise buildings, it is concerning from a perspective that also considers the importance of facilitating firefighting efforts. Evacuation of burning buildings commonly occurs at

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[126] Life Safety Laws, *Sprinklers in High-Rise Buildings* (Chicago: IREM, 2013), http://www.irem.org/File%20Library/Public%20Policy/LifeSafety.pdf.

[127] Larry Pigg, *Elevators in Emergencies: The Firefighter's Perspective* (Phoenix, AZ: Knox Company, 2013), http://www.knoxbox.com/store/files/ElevatorsInEmergencies_Pigg.pdf.

[128] Angle et al., *Firefighting Strategies and Tactics*.

[129] Laws, *Sprinklers in High-Rise Buildings*.

the same time as fire response.[130] Evacuation and firefighting efforts are especially likely to coincide in the case of high-rise buildings because, as mentioned earlier, evacuation of such buildings takes a very long time. The concern is not the lack of enough elevators for both firefighters and evacuees—reserving even two elevators for fire response units is likely resolve this situation—but rather that firefighting tactics must accommodate these changed circumstances. In particular, forcing evacuees to exit at roughly the same spot in the building as firefighters enter (as elevators usually cluster together) seems likely to slow fire response and make it more difficult for evacuees to exit the building quickly.

The terrorist, especially the terrorist intending to cause casualties among responders, may strike at high-rise buildings too fire-resistant to be targeted by an unsophisticated arsonist, or may strike with the intent of causing collapse rather than simply fire damage. Attacks presenting a serious risk of structural collapse necessitate complete evacuation of structures not intended to be evacuated.[131] Reliance on burnout may be misplaced if the conditions on which burnout predictions are predicated (e.g., that fire sprinklers will function normally and that laminated insulation panels will not serve as fuel) hold true. Sabotage of a building prior to an act of arson can prevent burnout or at least allow a fire to spread much further before burnout. Similarly, it is impossible to be certain that partial collapse will not occur, even with a very secure structure. Even if robustness allows planners to be relatively confident that a local collapse will not turn into a complete collapse, such a scenario necessitates at least partial, and probably full, evacuation of the structure. First responders who wish to be prepared to combat pyro-terrorism therefore must be prepared to evacuate buildings not intended to be evacuated.

D. COLLABORATION WITH OTHER AGENCIES

Some of the literature on responding to terrorist attacks has highlighted the importance of intelligence sharing and coordination with first responders to mitigate the

[130] Angle et al., *Firefighting Strategies and Tactics*; Iwona Cłapa et al., "Firefighters Ascending and Evacuation Speeds during Counter Flow on Staircase," *Safety Science* 78 (October 1, 2015): 35–40.

[131] Gershon et al., "Factors Associated with High-Rise Evacuation: Qualitative Results from the World Trade Center Evacuation Study"; Pigg, "Elevators in Emergencies: The Firefighter's Perspective."

threats presented by terrorists aiming for emergency personnel.[132] The lack of intelligence sharing is a fact lamented by scholars.[133] At least two sorts of intelligence-based mitigation are possible. The first is prospective mitigation of risks based on general intelligence available to law enforcement about likely targets and avenues of attack. For example, this sort of risk mitigation suggests that the Department of Homeland Security, knowing that a particular terrorist group is active in a city, and knowing that communications within this group have been exchanged about the possibility of arson and several possible targets, should share that information with the fire department responsible for responding to such attacks. However, numerous barriers to this sort of intelligence sharing abound, only some of which are easily resolved. In addition to the general inefficiency associated with inter-departmental information sharing, it is also possible that this sort of information sharing should require the disclosure of sensitive information, particularly information that may jeopardize the law enforcement response to the planned terrorist attack.

No less important, and likely easier to achieve, is intelligence sharing to facilitate a response to ongoing attacks. The importance of this sort of information sharing should be readily apparent from the previous discussion of the numerous ways in which terrorist arsons can be more dangerous than unintentional fires and even than less sophisticated arsons. To understand how to achieve this sharing, consider perhaps the most significant barrier to pre-incident information sharing between first responders and law enforcement or intelligence agencies is the risk that sharing information with first responders may jeopardize a law enforcement operation.

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[132] Keeley Townsend et al., "Intelligence-Led Mitigation," *Journal of Homeland Security and Emergency Management* 7, no. 1 (January 12, 2010), https://www.degruyter.com/view/j/jhsem.2010.7.1/jhsem.2010.7.1.1763/jhsem.2010.7.1.1763.xml.

[133] Ian I. Mitroff and Can M. Alpaslan, "National Insecurity," in *The Crisis-Prone Society: A Brief Guide to Managing the Beliefs That Drive Risk in Business*, ed. Ian I. Mitroff and Can M. Alpaslan (New York: Palgrave Pivot, 2014), 59–65.

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V. CONCLUSIONS

One of the major concerns that the author had in developing this thesis—one of the greatest challenges that he had to overcome—was that very little has actually been written about the threat of sophisticated arson of *any* kind against high-rises, to say nothing of the threat of pyro-terrorism. Were the author a scholar attempting to perform a quantitative inquiry into the potentially greater destruction that can be caused by a sophisticated arsonist with knowledge of a building's fire safety design and the skills necessary to sabotage that design, he would have been stymied by the almost complete lack of literature directly relating to this topic. Of course, "it's hard" is not much of an excuse for a scholar, but it is a problem for an academic who has identified a concern of pressing *practical* importance that should be addressed in the literature and in practice as soon as possible.

Even with that sound justification, though, it is difficult to present a large literature review as a thesis without significant analytic work leading to conclusions of importance. It is the author's position that this thesis presents just such analytic work, as well. In keeping with his goal of facilitating scholarly development of this topic in the future, he has identified the most pressing research needs and provides the following recommendations for both practical and scholarly work.

A. THEORETICAL WORK ON PYRO-TERRORISM

The academic community thus far has not taken seriously the concern that pyro-terrorism presents significant differences from other forms of terrorism.[134] Although some scholars have examined the risks of pyro-terrorism in detail, others have suggested that it is just one tool among many available to terrorists, and the possibilities it presents are not fundamentally different from those presented by, e.g., explosives. This suggestion is false. Thinking of arson as part of a static toolkit available to terrorists overlooks the latent possibilities for destruction and violence available to the sophisticated arsonist and

[134] Stuart Macdonald, "Assessing and Responding to the Cyberterrorism Threat," in *Terrorist Use of Cyberspace and Cyber Terrorism: New Challenges and Responses*, ed. Mehmet Nesip Ogun (Amsterdam, Netherlands: IOS Press, 2015), 201.

assuming that those possibilities remain forever dormant is naive and irresponsible. That terrorists have thus far not enthusiastically embraced the unique potential of arson as a weapon does not at all suggest that they will not do so at some point in the future; indeed, as countermeasures against explosives become more and more sophisticated, it seems likely that terrorists will turn to arson as a way of making use of more common and less detection-prone tools.

Some have suggested that the pioneering work of Baird and Deshpande discussing the possible proliferation of pyro-terrorism is at best needless fear mongering and at worst may actually suggest new forms of attack.[135] However, this fear is not well founded. Reviews of the literature with respect to terrorism predictions suggest that the more urgent danger is the potential for "failures of the imagination" like those that permitted the 9/11 hijackings.[136] Terrorists have proven adept at spotting vulnerabilities in the many targets available to them; suggesting that such vulnerabilities should not be discussed for fear of giving ideas to the terrorists encourages perpetuation of those vulnerabilities. Moreover, it seems simply false to suggest that terrorists may not discover on their own the potential of fire as a weapon, as Palestinian militants[137] have used fire as a weapon for quite some time.[138]

B. RISK ASSESSMENT

One critical concern for mitigating the threat posed by pyro-terrorism is allocating resources and understanding where the threat of pyro-terrorism is most significant. The theoretical framework offered by Deshpande for risk assessment with respect to pyro-

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[135] Boyd, "Protecting Sensitive Information: The Virtue of Self-Restraint"; Brian A. Jackson and Dave Frelinger, *Emerging Threats and Security Planning: How Should We Decide What Hypothetical Threats to Worry About?* (Santa Barbara: RAND, 2009), https://market.android.com/details?id=book-X60clSMyEIsC.

[136] Edwin Bakker, *Forecasting the Unpredictable: A Review of Forecasts on Terrorism 2000–2012*, (The Hague: International Centre for Counter-Terrorism, 2012), https://www.icct.nl/download/file/ICCT-Bakker-Forecasting-the-Unpredictable-July-2012.pdf.

[137] **NOTE:** it is the author's hope is that now that he has organized all the Israel forest fire information together, this one sentence does not seem out of place. It is intended just as a counterexample to the notion that this sort of article or thesis is giving the terrorists ideas.

[138] Kliot, "Forests and Forest Fires in Israel."

terrorism is sound, but should be extended beyond wildfire risk.[139] Some research has been done on quantifying the risk of pyro-terrorism in a particular case, but that research focuses on the protection of federal buildings in particular and may not easily be adapted to a broader context.[140]

In the interests of providing guidance for filling gaps in the literature, the researcher briefly discusses the characteristics that a framework suitable for evaluating the risk of pyro-terrorism should have. First and foremost, as both Neale and Deshpande note, such a framework should consider the physical vulnerability of a potential target. This vulnerability concerns more than just the vulnerability when all systems are functioning as designed. In the case of a sophisticated attack, such systems will often fail (and in fact, many such systems do fail through a lack of maintenance or poor design even when the attacker does not target those systems).[141] Such an analysis should consider at least the redundancy of fire protection and mitigation systems, the degree to which such protections or systems operate effectively even when response teams act incorrectly (as may be the case when an arson attack is disguised as a fire resulting from mechanical or human error, which reduced the perceived likelihood that it may expand beyond projections), and the degree to which such systems are physically protected from unauthorized access and potential sabotage.

Second, a framework for evaluating pyro-terrorism risk should consider the value of a potential target to terrorists, which, of course, considers the economic harm a terrorist may produce by attacking the target. However, recall the earlier discussion of the factors contributing to the relative preference terrorists seem to have for explosives over arson. A key consideration for a risk of terrorism is the symbolic victory that terrorists may obtain by destroying a target, and particularly, the symbolic victory they may obtain by destroying it in a particular *way*. For instance, the tallest buildings in a city are

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[139] Deshpande, "Pyro-Terrorism: Recent Cases and the Potential for Proliferation."

[140] Neale, "Performance-Based Design for Arson Threats: Policy Analysis of the Physical Security for Federal Facilities Standard."

[141] Collier and Baker, "The Influence of Construction Detailing on the Fire Performance of Polystyrene Insulated Panels," 195–211.

disproportionately valuable targets for pyro-terrorism simply because of the visual impact of seeing such a building on fire.

Third, such a framework needs to consider the ability of law enforcement and firefighters to respond to such an attack. This consideration itself has two prongs. With respect to a law enforcement response, a critical concern is the *perceived* likelihood of apprehending the terrorist (not necessarily the *actual* likelihood). Although the previous discussion suggests that terrorists are not encouraged by the relative low risk of certain kinds of arson, it is nevertheless probable that, given the choice between two targets, a terrorist may prefer the target most likely to preserve the ability to strike again. Consequently, if the vulnerable points of a particular target are in high-traffic areas or especially areas with security camera coverage, a target may be somewhat less vulnerable. With respect to firefighter and (to a lesser degree) medical response, a critical concern is the perceived efficacy of the firefighting departments responding to a contemplated attack. To be discussed in a later section, firefighter tactics can mitigate some of the advantages that arson holds for the terrorist; in any event, a better fire department is likely to reduce the effectiveness of any act of pyro-terrorism. It consequently seems likely that pyro-terrorists prefer targets protected by less sophisticated fire departments, all else being equal.

Finally, in line with the earlier discussion of second-wave attacks, a framework for assessing pyro-terrorism risk needs to consider the vulnerability of first responders responding to an attack on the target in question. This consideration is important for two reasons. First, attacks may be motivated by a desire to attack first responders, and targets at which first responders may be vulnerable are therefore more attractive targets. Second, and probably more importantly, is that a higher risk of pyro-terrorism necessitates a greater degree of physical security, greater robustness, and redundancy of sprinkler systems and similar mechanisms, and generally reduces the likelihood that a particular act of arson is effective. These measures make it more likely that, in the event that a terrorist attack is attempted and first responders are targeted, that attack is unsuccessful.

C. BUILDING CODES

The goal in developing building codes should be to produce (1) a hybrid performance-based and prescriptive framework, (2) a framework that is narrowly tailored to protect buildings at high risk without imposing unduly onerous requirements on other development, and (3) a framework suitable not just for minimizing the building's vulnerability to arson but also for standardizing characteristics of the structure that should not vary from building to building.

With respect to the first point, the reasons for preferring a hybrid performance-based and prescriptive framework are set out earlier and are not repeated again. Such a framework should include, at a minimum, performance-based standards for structural integrity, to include robustness in the face of a partial collapse, the requirement that fires, in the absence of accelerants, burn themselves out quickly enough to permit the survival of any persons trapped within the building, and human safety requirements like ventilation standards and flame-resistant, evacuable corridors. Once a hybrid framework is adopted, the performance-based standards should be set higher than what may be "realistic" at the time of the code's drafting, to encourage technological development and greater safety while also providing the alternative of defaulting to the prescriptions in the code.

With respect to the second point, an important concern arises. How should an anti-terrorism building code be applied to accommodate the fact that the usage of modern buildings is rarely certain when the buildings are constructed, and may in fact change over time? Perhaps more importantly, how can it possibly be applied to some vulnerable groups (e.g., religious minorities) without infringing upon Constitutional guarantees of political and religious neutrality? Consider one hypothetical code and two hypothetical cases in which that code cannot be applied reasonably. This hypothetical building code may have two tiers of requirements, one for especially at-risk buildings (e.g., governmental buildings, hospitals, and so on) and one for buildings not judged to be at risk of pyro-terrorism.

In the first hypothetical instance, it is possible to run into legal problems if certain at-risk groups are treated differently from the general population. Imagine, for instance, that anti-Jewish terrorism is on the rise, and it is consequently determined (by some viewpoint-neutral and thus constitutional rubric) that synagogues are especially vulnerable to terrorism. Synagogues are then subjected to greater requirements than other religious or nonreligious groups based solely on their vulnerability to terrorism, which—although well-intentioned—is almost certainly not permissible under First Amendment jurisprudence.

The second hypothetical situation reveals another problem with this approach. Imagine that a particular building is constructed according to the lower standard (for instance, because it is a single-use office building owned entirely by one company) and then gradually becomes higher risk over time. This scenario may happen because part of the building is sold or leased, which makes it a multi-use building and thus more valuable as a target. It also happens because the corporation holding the building becomes politically unpopular with certain groups and is targeted for that reason (for instance, if the corporation is a biotechnology firm that experiments on animals or uses stem cells). No good options exist for the regulatory body seeking to enforce its fire safety code in such a circumstance.

The solution is to adopt a several-tier approach, one based primarily on the inherent attractiveness (to terrorists) of certain purpose-built structures and on structural vulnerabilities of other structures. This approach at least is made up of three tiers. The first—the tier requiring the least in the way of fire safety measures—are buildings below a certain height in stories or maximum occupancy, or in areas of lower population density (i.e., not in the center of a city). These are not likely to be at an inherently high risk of terrorism; moreover, even if they are burned, the human cost and economic damage to both is relatively lower than in the case of larger, higher-occupancy structures, especially considering it is easier to put out a fire in a smaller building and easier to evacuate such a building.

The second tier is used for buildings not inherently attractive to terrorists because of some political or symbolic significance to a successful attack, but which nevertheless

suffers significant damage and risk many lives if attacked. Buildings in this category include most buildings in city centers, and certainly all high-rise buildings. Although these buildings may lack inherent significance to a terrorist, keep two considerations in mind. The first is that because of their propensity to become multi-function buildings or to change ownership with the economic tides, they are somewhat likely to become attractive targets to terrorists, for the reasons discussed previously. The second consideration, though, is more important. Even if the risk of terrorism against a building in this tier is no greater than in the first tier (which is unlikely) the potential costs of an act of pyro-terrorism against a large building in a city center are far greater. Such buildings are more expensive, more populated, and have less space around them, which makes them more likely to damage other buildings as well.

The third tier is for purpose-built buildings not likely to change hands, can be lawfully singled out for special treatment by regulators, and is likely to be attractive to terrorists. Governmental buildings (especially federal buildings), schools, hospitals, and the like all fall into this category. Within this tier, of course, the architectural characteristics of the structure are taken into account.

With respect to the third point that a building safety framework should exhibit, it is important to consider the potential uses for prescriptive elements of a building code. In general, the author supports the availability of performance-based alternatives for most building safety provisions; however, he acknowledges that in some areas, performance is difficult to measure or standardization is necessary. One example of the former is the requirement that commercial buildings have standardized exit signs. Such a requirement can be supplemented by a performance-based alternative (e.g., that commercial buildings must have some way of clearly identifying safe exit paths), but measuring effectiveness at satisfying that requirement can be difficult, if not impossible. It seems likely that most safety measures related to human behavior and responses to a fire need to be prescriptive rather than performance-based.

The second case in which prescription is essential is where standardization is necessary. An example presents itself in that standardization is often necessary to support a tactical firefighting response. So-called “glowing walkways” are intended to light up

smoky corridors so that firefighters can navigate them safely. More effective way of doing so may be available, but firefighters are trained to respond to the glowing walkway design, and so it should be mandated to enable firefighters to respond as they have been trained.

A final point that the author wishes to raise in the conclusion is that providing a schematic outline of an ideal building safety code is not all that is needed for regulators to mitigate the risks of pyro-terrorism successfully; they should also have a robust set of tools to use in "filling in" that outline. The author makes two recommendations The first is the adoption of a mixed-methods analysis of existing fire prevention systems, both in the development of new codes and in updating those codes. The second is the adoption of a method for identifying hypothetical fire scenarios and revising codes based on those scenarios.

A mixed qualitative and quantitative analysis of past fires can be illustrative in identifying failure points in fire prevention systems and codes.[142] Such approaches have been considered with respect to fire chronologies. A fire chronology is essentially a timeline of the development of a past fire. In developing such a timeline, investigators seek to answer questions like "why was the fire able to move from its starting point to some other point of vulnerability, and how could we revise our countermeasures to prevent this in the future?" A mixed-methods approach to fire chronologies allows investigators also to consider witness statements and interviews with survivors of the fire. This last point can be especially important because a critical concern in fire safety is not just how the physical structure responded to the fire, but also how victims behaved, and what behaviors allowed them to escape or impeded that escape. This point is especially relevant when it comes to developing safety codes intended to mitigate the risk of arson designed to kill the inhabitants of a building.

Other measures of fire performance, applicable in retrospect, may also be highly useful in such cases. Chief among these is the "temperature history," a fire chronology in

[142] Nils Johansson, Patrick van Hees, and Stefan Särdqvist, "Combining Statistics and Case Studies to Identify and Understand Deficiencies in Fire Protection," *Fire Technology* 48, no. 4 (October 1, 2012): 945–960.

which temperature loads—that is, the heat released by the burning of fuel available in a given space, commonly a single room—are calculated based on structural fuel and any fire mitigation like sprinklers.[143] This form of fire chronology is especially useful because the strictly quantitative, scientific nature of the analysis also allows investigators to consider questions like "how would the temperature load have changed if the timber supports had delaminated and combusted?"

Such hypothetical questions are highly relevant when designing safety systems for arson. The majority of fires are either accidental or the product of unsophisticated arson, meaning that much more data is available on how such fires will progress. By examining hypothetical questions (e.g., "how would this fire have been different if the sprinkler system had been sabotaged, causing it to not work properly?"), regulators can take lessons even from accidental fires that are relevant to the mitigation of pyro-terrorism.[144]

Mixed-methods approaches have already been applied to the development of fire safety codes through the use of fire scenarios.[145] A framework for developing fire scenarios to inform fire safety protocols and codes is discussed, and it should be adapted to accommodate the special risks presented by sophisticated arsonists.[146] Such a framework may consist of the identification of plausible accidental fires—as already occurs—and determine whether those fires can be made more severe through sabotage of mitigation systems. It also requires the identification of fire scenarios that are only likely if a fire is intentionally set, and assess the plausibility of such scenarios. The consideration of such hypothetical scenarios is not just essential for evaluating a building's safety against arson; it also can assist in the training of fire response teams.

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[143] Kevin J. LaMalva and Morgan Hurley, "Determination of Temperature Histories for Analysis of Structural Response to Fire," in *Structures Congress 2015* (Reston, VA: American Society of Civil Engineers, 2015), 819–828.

[144] Martin Nilsson, Nils Johansson, and Patrick Van Hees, "A New Method for Quantifying Fire Growth Rates Using Statistical and Empirical Data—Applied to Determine the Effect of Arson," *Fire Safety Science* 11 (2014): 517–530.

[145] Neale, "Performance-Based Design for Arson Threats: Policy Analysis of the Physical Security for Federal Facilities Standard."

[146] Nilsson et al., "Analysis of Fire Scenarios in Order to Ascertain an Acceptable Safety Level in Multi-Functional Buildings."

D. TACTICAL MITIGATION

This section lays out the conclusions that can be drawn from the earlier discussion about firefighter tactics in responding to high-rise fires and especially in response to cases of pyro-terrorism. It provides a research agenda for future investigation, because some questions have not yet been empirically investigated with sufficient depth to formulate policy recommendations. It also provides a set of schematic guidelines for the development of tactical mitigation strategies for the risks posed by these challenges.

1. Evacuation

Based on the difficulty of evacuating ultra-high-rise buildings on foot, it seems that at least some elevators in ultra-high-rises should be used for evacuation. Therefore, a gap in the literature exists with respect to two questions. First, how can the use of elevators when evacuation needs are urgent be managed efficiently? Most elevators are not equipped with the technology necessary to determine that people are remaining on the floor to be evacuated. Will evacuation depend on which floors can get to the elevator buttons most quickly? It is also likely that some people will want to leave before their elevator is completely full, even if others are waiting to evacuate. The question of what technical system to put in place to ensure that elevators are used effectively in evacuations is one that should be reserved for scholars studying crowd behavior and the use of technology to manage crowds.

Just as significant is the second question, which is a question of pedagogy. In the United States, at least, it is drilled into the heads of children that they should never use the elevators in a fire; they should use the stairs, instead. Overcoming that education will doubtless be difficult, as will convincing evacuees that it really is safer to wait 10 minutes on the same floor than to take the stairs to the ground floor.

A final question that is not pressing now but will be in the future is how to protect elevator shafts from sabotage. Elevators have robust safety mechanisms in place to prevent them from falling or otherwise injuring their inhabitants. They generally err on the side of stopping in place rather than proceeding upwards or downwards when it might be risky. Under ordinary circumstances, this situation occurs, as it should. If elevators

become a major method of evacuation, however, an elevator that will shut itself down readily may become a deathtrap at the slightest hint of sabotage. Moreover, evacuees relying on the sabotaged elevators may be prevented from evacuating the building before the fire spreads.

2. Intelligence-Sharing and Pyro-terrorism

One of the key concerns discussed earlier is the difficulty of sharing intelligence related to potentially sensitive questions of homeland security with departments that do not ordinarily have a homeland security role (for instance, fire departments). As was discussed previously, wholesale sharing of potential terrorist targets in a particular municipality runs a serious risk of alerting terrorists that their communications or plans have been intercepted. What is needed is a method by which information specific to pyro-terrorism can be shared with fire departments, in advance, when it is clearly related to pyro-terrorism, or during a fire, where a burning building had been previously identified as a potential target of any sort of terrorism.

Suppose, therefore, that instead of immediately sharing intelligence with fire departments when they become aware of an elevated potential for acts of terrorism, intelligence agencies instead track three things. The first is the general location (an entire metropolitan area, for instance) in which an instance of pyro-terrorism is considered more likely. The second is the specific addresses at which pyro-terrorism is considered more likely. The third is the specific addresses at which any sort of terrorism is considered more likely. Fire departments, for their part, can conduct risk assessments within their area of responsibility and focus on high-profile buildings, to assess vulnerability to pyro-terrorism and also to formulate the most likely pyro-terrorism scenarios (versus accidental fires and unsophisticated arsons).

In responding to large fires, the fire department determines, first, whether the fire is in a structure identified as being at high risk of pyro-terrorism, and second, whether the fire is behaving unusually compared to predicted fire scenarios (by way of example, originating in an unlikely place or spreading more quickly than predicted). If either are true, the fire department must notify the responsible intelligence agency; even if neither is

true, the fire department should inform the responsible agency of the address at which the fire occurred. The intelligence agency responds by disclosing its relevant information: (1) if the address reported for any fire is one of the addresses at an elevated risk of pyro-terrorism, (2) if the address reported for an unusual fire is one of the addresses at an elevated risk of terrorism, (3) if the address reported for an unusual fire is within a metropolitan area at an elevated risk of pyro-terrorism, and (4) if the address reported is identified by the fire department as being vulnerable to pyro-terrorism and is within a metropolitan area at an elevated risk of pyro-terrorism.

E. SUMMARY

This thesis has established a pressing need for a wide range of theoretical and practical changes to protect against the threat of pyro-terrorism better. Needed developments are a framework of a building's risk of being targeted by terrorist arson, suitable for application to cost-benefit analyses and security agency risk management teams, a building code framework that enables regulatory bodies to account for the risk of pyro-terrorism when assessing development projects, a method by which fire chronologies may be adapted to assess the possibility that pyro-terrorism is involved, a mixed-methods analysis of potential future pyro-terrorism events as "fire scenarios" to enable the development of specific pyro-terrorism countermeasures for high-risk buildings, research into the capabilities of currently used and potential future communications systems for firefighters, pedagogical and systems analyses of the possibility of using high-speed elevators for high-rise evacuation where necessary, and an information-sharing system by which departments with access to sensitive information can share that information with fire departments as needed without jeopardizing security by revealing that information wholesale.

Some potential solutions to these problems have already been considered, and the solutions that have been discussed in this thesis, schematic as they necessarily are, appear to this author to be sound. It is hoped that these solutions prove to be a sound jumping-off point for future scholars who wish to tackle these issues. Tentative recommendations have also been provided, which may be for departments of security or fire departments to

address rather than the scholarly literature. These practical recommendations focus more on the potential avenues available for improving fire safety that have already been discussed in the literature, or else approaches that are clearly likely to be effective based on indirect evidence in the literature.

The greatest value of this thesis, though, lies in demonstrating the risk of an avenue of attack that has thus far not been exploited by terrorists to any significant degree. Despite the advances in firefighting tactics and technology and the safety improvements provided by building safety codes, a sophisticated arsonist can cause a great deal of harm, in terms of economic damage, lost civilian lives, and first responder casualties. Even without considering the recommendations presented in this thesis, it is valuable because of its potential to prevent "failure of the imagination" scenarios, like those that allowed the 9/11 attacks to succeed.

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