Inquiry: The University of Arkansas Undergraduate Research Journal

Volume 9 Article 7

Fall 2008

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FACTORS AFFECTING THE SPREAD OF A BIOTERRORIST AGENT THROUGHOUT A BUILDING

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Abstract

Bioterrorism has become a greater concern for Americans since the 2001 anthrax letters. Recent studies have explored the possibilities of biological attacks, and most deal with possible large-scale attacks. However, there is reason to believe that small-scale attacks are more likely. Even though there have been investigations of the postal delivery system and the spread of bioagents through mail, few if any studies have looked at an attack on a single building and the resultant spread from room to room. One particular method of attacking a building would be a single-event release of an aerosol bioagent in the building. This paper describes the development of a method for studying the spread of an aerosol throughout a building in order to determine what factors most affect the time between release and the lethal exposure for an occupant in various locations. A multi-zone airflow model, CONTAM, was used to simulate and compare the effects of the air handling system operation, door position, building level, predominant wind direction, and other factors. It was found that the air handling system, building floor level, and door position changed the time to lethal exposure. For the scenarios investigated, lethal exposure times ranged from 5 seconds to nearly 15 minutes, and the air handling system was found to have the greatest effect on a contaminant's spread through a building.

Introduction

Throughout history, biological weapons have been used to wage war. One of the earliest and possibly deadliest examples occurred in the mid-1300s in Kaffa as bubonic plague victims of the Tartar army were catapulted over the city walls. Some believe that this is what led to the epidemic throughout medieval Europe that killed 25 million. The twentieth century saw the rise of research into biowarfare among nations across the world. This led to the signing of the 1972 Biological Weapons Convention, which forbids research with offensive biological agents and stockpiling bioweapons for military purposes [1].

Bioterrorism has become a concern for everyday Americans following the September 11, 2001 attacks on the World Trade Center. The first incidents involving anthrax occurred on September 25, 2001, when an assistant to Tom Brokaw (NBC anchorman) began to develop cutaneous anthrax after handling a letter containing anthrax powder. By November 2, 2001, the Center for Disease Control (CDC) had reported 21 cases of anthrax –16 confirmed and 5 suspected [2]. Anthrax is classified as a Category A bioterrorism agent. There are three categories of possible bioterrorist diseases or agents. Category A Diseases/Agents are the highest priority risks. These agents are the worst because they can be transmitted easily, result in high mortality rates, have potential for major public health impacts, and require special action for public health preparedness. Currently there are six listed by the CDC in Category A: Anthrax, Botulism, Plague, Smallpox, Tularemia, and Viral Hemorrhagic Fevers. Category B Diseases/Agents are moderately easy to disseminate, have low mortality rates, and require enhanced disease surveillance by the CDC. Category C Diseases/Agents are those considered to be available for mass dissemination, are easily produced, and have potential for high mortality rates. [3]

A large-scale release into the atmosphere or over a large city is greatly feared. For example, the release of 100 kg of anthrax over a large city could kill millions [4]. Large-scale attacks have been attempted by terrorists in the past, but all have failed. For instance, the Japanese doomsday cult Aum Shinrikyo failed on ten separate occasions at an open-air urban attack of anthrax or botulism, despite having considerable wealth and scientific capabilities. In March of 1995, the cult eventually killed 12 people through the release of sarin nerve gas in a Tokyo subway. Experts believe that in the near term, it is considered more likely that terrorist attacks will be small-scale attempts or merely hoaxes. [5]

Problem Statement

The misuse of a building's ventilation system to spread a biological agent throughout a building is a real possibility [6]. The purpose of this study was to simulate various small-scale attack scenarios on a typical 'office' building. The time between bioagent release and the time at which an occupant is exposed to a lethal dose were compared for various scenarios. In addition, the importance of building related factors such as air handling system (AHS) operation, building floor level, door position (open or closed), and predominant wind direction were analyzed.

Modeling Method

The use of airflow model techniques was determined to be the best approach for this undergraduate research project.

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The National Institute of Science and Technology developed and maintains a model that was originally designed to analyze building ventilation and indoor air quality issues. This computer simulation model is known as CONTAM and is a multizone airflow and contaminant transport model capable of determining zonal airflows, contaminant concentrations, and personal exposures rates [7]. Using CONTAM to evaluate potential building terrorism is a logical extension of its application. It has more recently been considered an appropriate tool for such building simulations [8-11]. Other published works [12-14], only somewhat related, are recent studies on exposure to passengers, airflow and pathogen transport within aircraft cabins.

For this study, a simple building was sketched to model several different scenarios. The building is two stories tall with both floors having a large open space in the center that is meant to represent a cubicle area. On each floor and along the two opposite sides, are smaller rooms representing individual offices. In Figure 1, the CONTAM sketches for each floor are shown. CONTAM inputs included sizes for walls, ducts, and airflow paths (windows, doors, wall leakages, cracks, etc.). Mechanical systems such as ducts, fans, and zone sizes are also inputs. In addition, information on the tracked contaminants (i.e., biological agents) was input along with the location and method of entering the building.

Depending on the scenario, a burst contaminant source was placed in either a 1st floor office (location A) or a 1st floor maintenance room (location B). The source considered was an aerosol burst of 0.4 kg contaminant into the model at 10:00 AM. Simulations were run with doors in the building either all open or all closed. Exposure results were calculated in 1st and 2nd floor offices (locations 1–2) and in 1st and 2nd floor cubicle areas (locations 3–4), resulting in a total of 16 simulated scenarios. The burst source is representative of an aerosol release of a bioagent. The office was chosen to represent a release location with full air-conditioning ventilation and return; in contrast, the maintenance room has no air-conditioning ventilation or return.

CONTAM exports results for simulated bioagent concentrations for every zone at each time step. Five second increments were chosen as the time step for these simulations and found generally to capture the lethal exposure time scale. To determine exposure for a person in each room, a spreadsheet was used to integrate the data. These calculations were based on an inhalation rate of 20 m3/day [15, 16] and a mean lethal dose (LD50) of 0.01 micrograms. The LD50 value chosen was calculated for Inhalation Anthrax from the low end of the University of Alabama, Birmingham's LD50 estimate of a 10,000-20,000 spores [16] and Ed Lake's concentration estimate of one trillion spores per gram [17]. For the calculations, a 1% solution was assumed for the aerosol device, so the times until lethal exposure were based on 1 microgram of aerosol exposure.

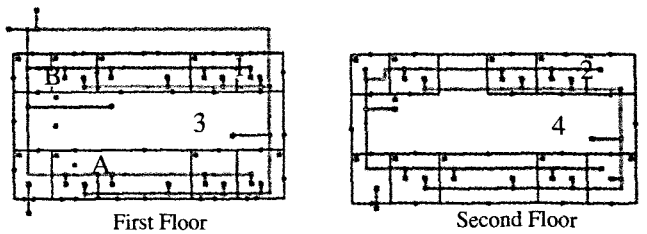

Figure 1. CONTAM two-story office building sketch with indicated release (A: 1st floor office and B: 1st floor maintenance room) and exposure (1: 1st floor office, 2: 2nd floor office, 3: 1st floor cubical area. and 4: 2nd floor cubical area) locations.CONTAM

Results and Discussion

Lethal Exposure Time:s

Table 1 contains the resulting times until lethal exposure (LD50) for each of the 16 simulations. The table is organized based on where the contaminant was released (office or maintenance), where exposure was calculated for an occupant (1st floor office, etc.) and whether the doors in the building were open or closed. The data are listed in minute:second (mm: ss) format.

For each room, the contaminant level and exposure level had similarly shaped curves as functions of time. Figures 2a-b are representative: Figure 2a is for the scenario in which the biocontaminant originated in a 1st floor office and all doors were open with exposure measured in the 1st floor cubicle area. Figure 2b displays similar conditions except the contaminant originates in the 1st floor maintenance room. Note that the graphs are given over a much larger time range than the time required to lethal exposure.

Table 1. Time to Lethal Exposure (mm:ss)

		Exposure Location							
		1st Floor Office (Location 1)		1st Floor Cubicles (Location 3)		2nd Floor Office (Location 2)		2nd Floor Cubicles (Location 4)	
Doors Open/Closed:		Open	Closed	Open	Closed	Open	Closed	Open	Closed
Contaminant Origin	Office	00:40	00:35	00:05	00:10	00:55	00:40	1:25	01:05
	Maintanence	04:40	06:10	00:45	00:55	08:35	08:05	12:35	14:45

Building Factors:

The effect of the AHS can be seen by comparing exposure times between scenarios with the contaminant originating in the maintenance room (with no ventilation) and the office (having ventilation). For an exposure in the same room, it would take 5 to 14 times as long for a lethal dose to be reached when the contaminant burst originated in the maintenance room as compared to the office. For contaminants originating in the office, the longest time to lethal exposure was 1 minute 25 seconds, occurring in the second floor cubical area with all doors open. No matter the scenario, a release in the office had some of the agent immediately drawn into the AHS and quickly distributed throughout the building. The worst maintenance room release case occurred with all doors open. The time to lethal exposure time was 45 seconds in the adjoining cubicle area. For most

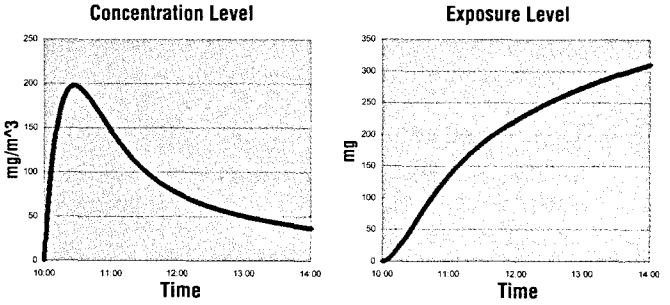

Figure 2a. Contaminant concentration and exposure level vs. time for 1st floor office release to 1st floor cubicles exposure.

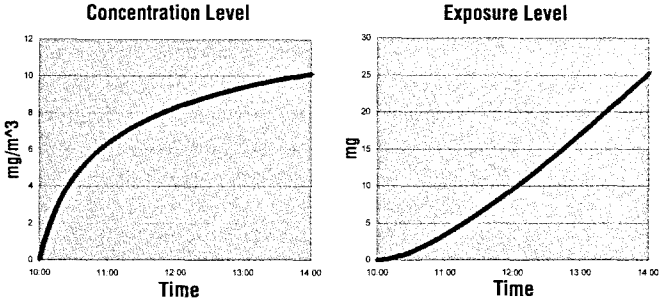

Figure 2b. Contaminant concentration and exposure level vs. time for 1st floor maintenance release to 1st floor cubicles exposure.

maintenance release cases, however, several minutes passed before lethal exposure time was reached. This was because the contaminant would have to first exit the maintenance room before it could be spread through the building within the AHS.

The AHS was the most dominant factor; however, the level (or floor) an occupant is on (relative to the contaminant release location) was also found to be important. The longest time until lethal exposure occurred when burst contaminant originated in the maintenance room. Of course, the longer the time to lethal exposure, the more opportunity to evacuate. If the biological release originated in an office, a person would become lethally exposed by simply traveling through the first floor cubicle area. When the release originated in the maintenance room, however, the contaminant level in the cubicles might be low enough for a period of time for occupants to leave the building. Further, it was expected that, with a contaminant originating on the first floor, the exposure times on a different floor would be nearly equal in each room. The second floor cubicle area consistently had longer exposure times than the second floor office room. This is suspected to be caused by unequal air circulation between the rooms. If one room has a higher air exchange rate, it would follow that the AHS would deliver a contaminant to that particular room at a higher rate as well.

Having open or closed doors affected the outcome the least. In general, longer times to lethal exposure occurred with doors closed when the exposure concern was in the adjoining room to the release point. The same was true (all doors closed) in nearly every case where the contaminant originated in the maintenance room. When the contaminant originated in the office room, having the doors open was better in every exposure room excluding the adjoining cubicle area. This was due to the fact that some of the contaminant escaped through open office door (into the cubical area), leaving less to enter the AHS which supplies the rest of the building.

Conclusions and Recommendations

Simulations for common elements of a two-story office building computed times for occupant lethal exposure that ranged from a few seconds to just over 14 minutes. Shorter times corresponded to open rooms on the same floor and near the release. Longer times to lethal exposure corresponded to rooms on floors different from the release point and when the contaminant was released from rooms without ventilation. The study shows the critical nature and importance of protecting against small-scale bioterror attacks in buildings. This means that an increased ability to detect bioagents is needed. Sensing technologies must be developed to detect quickly various agents at low concentrations. In the event of a biological release in a building, it is clear that one operating strategy is to shut off AHS as soon as a threat is detected.

Many effects that were not considered in this study could be further studied with CONTAM. These include the effects of outside windows, shutting off an AHS after release of an agent, filters and filter efficiencies, multiple AHS within a building, etc. To be fully prepared for the type of bioterrorist attack examined in this study, a model of a specific building should be made, and multiple scenarios should be run for that particular building to determine what procedures will minimize the occupant's exposures.

References

1. "History of Biowarfare and Bioterrorism." Arizona Department of Public Health Services. http://www.azdhs.gov/phs/edc/edrp/es/bthistor2.htm.
2. "History of Bioterrorism; A chronological History of Bioterrorism and Biowarfare Throughout the Ages." Biological Terrorism Response Manual. http://www.bioterry.com/HistoryBioTerr.html.
3. "Bioterrorism Agents/Diseases (by Category)." Centers for Disease Control and Preparedness. http://www.bt.cdc.gov/agent/agentlist-category.asp.
4. "Anthrax." NMS Bio-Defense. http://www.nmsbiodefense.com/hazards/bio_anthrax.htm.
5. Tucker, Jonathan B. "Historical Trends Related to Bioterrorism: An Empirical Analysis." Emerging Infectious Diseases. Volume 5. Number 4. Centers for Disease Control and Preparedness. http://www.cdc.gov/ncidod/eid/vol5no4/tucker.htm.
6. Kowalski, W J. "Defending Buildings Against Bioterrorism." Engineered Systems. Oct 2002. pg 61-68.
7. "NIST Multizone Modeling Website", National Institute of Science and Technology (NIST), <http://www.bfrl.nist.gov/IAQanalysis/index.htm>.

8. Chen, Qingyan (Yan). "Protecting Buildings from Chemical and Biological Warfare Agent Attacks – A Long Journey." HVAC&R Research. Vol 10 No 4. Oct 2004. pg 389-391.
9. Reshetin, Vladimir P. and James L. Regens. "Simulation Modeling of Anthrax Spore Dispersion in a Bioterrorism Incident." Risk Analysis. Vol. 23. 6 Nov 2003. pg 1135-1145.
10. Yeboah, F. E., et al., "Protecting Buildings Against Bioterrorism – Review of Guidance and Tools", ASHRAE Transactions, DA-07-029, 2007, pg 263-272.
11. Cheong, K. W. D., et al., "Measurement and Computations of Contaminant's Distribution in an Office Environment", Building and Environment, Vol. 38, 2003, pg 135-145.
12. Lin, C. H., et al., "Numerical Simulation of Airflow and Airborne Pathogen Transport in Aircraft Cabins – Part I: Numerical Simulation of the Flow Field", ASHRAE Transactions, OR-05-8-4, 2005.
13. Lin, C. H., et al., "Numerical Simulation of Airflow and Airborne Pathogen Transport in Aircraft Cabins – Part II: Numerical Simulation of Airborne Pathogen Transport", ASHRAE Transactions, OR-05-8-5, 2005.
14. Naiping, G. and Jianlei, N., "Improvement of Facial Humidity and Reduction of Pollutant Inhalation in Commercial Aircraft Cabins via Application of Personalized Ventilation", ASHRAE Transactions, SL-08-004, 2008.
15. "Risk Assessment: Frequently Asked Questions." Mid-Atlantic Risk Assessment. 7 Mar 2007. <http://www.epa.gov/reg3hwmd/risk/human/info/faq.htm>
16. "Anthrax Summary." AUB – Bioterrorism. Accessed 24 Apr. 2007. <http://www.bioterrorism.uab.edu/CatagoryA/Anthrax/summary.asp>
17. Lake, Ed. "Were the Anthrax Spores Coated with Silica or Not?" 8 Dec 2003. rev. 17 Aug 2004. online. <http://www.anthraxinvestigation.com/coatings.html>

Mentor Comments:

Dr. Darrin Nutter highlights Andrew Cantrell's independence and the breadth of knowledge required to complete this innovative research project.

As an undergraduate student in mechanical engineering at the University of Arkansas, Mr. Andrew Cantrell was awarded an Honors College Undergraduate Research Grant for the research described in this paper. Andrew, currently in the United States Navy, was a hard working and well disciplined student. The research required learning the fundamentals of aerosol dispersion, existing literature, building air-conditioning systems, and the modeling software (CONTAM) that is made available by the U.S. National Institute of Standards and Technology. Andrew's research was completely independent and took about a year and a half to complete. As the advisor, I provided guidance, structure, and expertise for Mr. Cantrell to complete his research. The research topic is unique and not addressed in the available literature. I encouraged the publication of Andrew's work. Finally, it should be noted that even though the presented work could be perceived as sensitive, it is important to publish. Understandings of the research findings should be used in a proactive way and to emphasize the importance of developing the necessary sensing technologies related to prevention and aerosol bioagent spread minimization within a building.