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EMS CONTAMINANT ISOLATION ENG.

by

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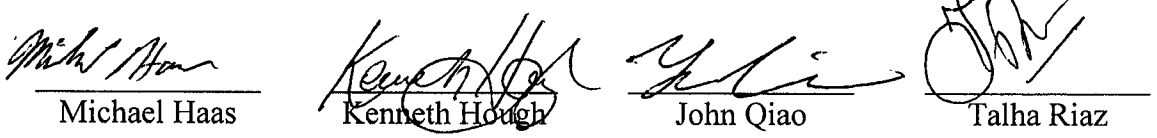

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ABSTRACT

Isolation and control of bodily substances is an important aspect of pre-hospital emergency care. Proper decontamination is required to ensure safe working and transporting environments for both the healthcare provider and patient on the ambulance. Current methods for disinfecting the ambulance and its respective equipment after calls have room for improvement. We have collaborated with Worcester Emergency Medical Service (WEMS) paramedics to identify the need for better cleaning procedures, and therefore equipment that are better designed to remove contaminants. Common pathogenic risks present to both Emergency Medical Service (EMS) personnel and their patients were analyzed. Appropriate decontamination procedures and personal protective equipment were researched. Alternative and effective disinfection methods and equipment along with preventative measures were considered and recommended.

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ACKNOWLEDGEMENTS

First off we would like to thank the University of Massachusetts Memorial Hospital Worcester Emergency Medical Service paramedics for giving us insight into their concerns with ambulance sanitization. We are in debt to Linda J. Gosselin from Massachusetts Emergency Care Training Academy for her input and opinions on current procedure, protocols and provisions for prehospital care. Last but not the least, we would like to thank Professor Mustapha Fofana for all his support with our project. Our constant exchange of thoughts with him helped us organize our ideas in a presentable fashion.

CHAPTER 1. EMS AND LIFE-SAVING PRACTICES

1. Introduction

Emergency Medical Service (EMS) has existed in the United States for over 97 years, going as far back as volunteer squads in World War I. Since then, many changes have been made that are significant improvements to the EMS system. These include the development of national standards for pre-hospital emergency care, the development of federal guidelines for ambulance design and installed equipment, and the adoption of proper emergency care procedures for each municipality, district or county in the US. However the aforementioned advances are only a few of the nation-wide changes made to EMS protocol; many other improvements have been made in different aspects of the system, such as equipment design and the medical science. However, there are still a handful of shortcomings to the EMS system that endangers both the patient and the provider in the field that need to be addressed.

Amongst the many different issues in today's EMS system – ranging from ergonomic problems to contamination threats – the most serious is the constant pathogenic risk to which both the worker and patients are exposed. This project aims to identify shortcomings to the contamination prevention aspect of the EMS system, not only to bring public attention to the neglected problem, but to also propose solutions to it. In order to adequately address said threat we have collaborated with Worcester Emergency Medical Service (WEMS) paramedics to identify them. Of the many issues discussed, isolation and control of bodily substances were of universal concern amongst all healthcare providers but face greater limitations in a mobile and fast-paced environment such as in the ambulance. Proper decontamination is required to ensure safe working and transportation environments for both the healthcare provider and patient in the ambulance. However, thorough decontamination can take time, and on many occasions

emergency calls can pile on top of each other, thus requiring ambulances to respond with minimal cleaning. Our project has two major goals: (1) to research and recommend designs for better body substance isolation systems and (2) to revise current cleaning procedures by the use of alternative equipment that effectively remove and prevent further accumulation of pathogens.

This project investigates the many findings we have researched, not only to address them, but to propose solutions that we hope may one day be implemented. Chapter 1 is the introduction of the research and project. Chapter 2 includes some history and necessary background to the EMS system. It then describes current pathogenic risks present to both the emergency care technician and the patient. The chapter delves into the different modes of transmission and the types of pathogens present that are a current or a potential threat. Chapter 2 ends with a brief presentation of documented cases of occupational exposures among health care workers to such pathogens and currently available decontamination methods. Chapter 3 includes a discussion of new technology that could detect and even identify pathogens, which may one day be practical in a pre-hospital setting. It then introduces different solutions and recommendations we make to minimize contamination issues for both the emergency care technician and the patient. The chapter then analyzes the mentioned solutions for viability and practicality in a pre-hospital setting, concluding with our final recommendation for lowering pathogenic risk. Finally, chapter 4 summarizes the whole of our research and investigation, and identifies potential shortcomings of our project while suggesting areas in which further research might be beneficial.

CHAPTER 2. EMS AND PATIENT-CENTRIC QUALITY CARE

2. Introduction

An important aspect of emergency medical service (EMS) is to provide appropriate and adequate care for the patients. Their condition must be stabilized and transported before conditions deteriorate rapidly. The presence of pathogens inside an ambulance, however, not only poses a threat to the workers but also has the potential of worsening the patients' condition and potentially leading to complications. This is of particular interest in an age where anti-microbialcides and other sanitizing agents are being extensively used. Many children are more prone to diseases that were once less of an issue (Edge, M. J., et al., [1]). Early exposure to pathogens provides anamnestic response to secondary exposure (Crowther, R. J., [2]), but not every patient is guaranteed to be immune to many pathogens, thus reinforcing the need for efficient sanitization methods for all persons present in the ambulance.

Our project plays an important role in an attempt to pave the path for better patient-centered quality care. Patients are transported in a small environment, which provides an excellent arena of transmission for many different types of contaminants. Pathogens on the stretcher and other medical gear that have not been adequately decontaminated pose a threat to not only the healthcare providers in the ambulance, but also to the patient. The need to provide a clean environment is critical. To fully understand the current state of the EMS system, it is necessary to know some history of how it developed.

The EMS system started off as organized volunteer squads in World War I, using motorized vehicles to transport injured soldiers. Later in World War II, military trained corpsmen provided basic care and transport to field hospitals staffed by physicians and nurses. By the time of the Korean War, field medics were trained and deployed along with medevac helicopters to transport

the wounded to nearby Mobile Army Surgical Hospital units where immediate emergency care was provided. Such advances were unfortunately solely for the military and quality of emergency care for the sick and injured back home varied as late as the early 1960s. Certain locations had ambulance services that were provided by well-trained personnel, similar to modern ambulances and equipment. A few places had prehospital emergency care provisioned by hospital interns. However, ambulance services in most places were provided by police, fire or local funeral homes that would convert their hearses or wagons to carry a cot. Not surprisingly, ambulance services were primarily for transport and no formal provision for prehospital emergency care existed. Quite often, patients with an acute illness were transported by their relatives and met with their family physician or on-call hospital physician because not all hospitals back then were staffed for emergency medical care (Pollak, N. A., [3]).

In 1966, the publication *Accidental Death and Disability: The Neglected Disease of Modern Society* by the Institute of Medicine brought to attention the serious inadequacy of pre-hospital emergency care and transportation in many areas of the United States. As a result, Congress mandated the National Highway and Traffic Safety Administration (NHTSA) of the Department of Transportation (DOT) and the Department of Health and Human Services (DHHS) to address the issues mentioned in the publication through the Highway Safety Act of 1966 and the Emergency Medical Act of 1973. Some of the nationwide improvements made were (Pollak, N. A., [3]):

1) Development of national courses of instruction for EMS, Fire, and Police personnel.
2) Development of nationally accepted textbooks and training aids for said courses.
3) Development of federal guidelines for ambulance design and equipment carried.
4) Development and adoption of service guidelines.

5) Adoption of proper emergency care procedures for each municipality, district or county in the US.
6) Establishment of hospital emergency departments that are adequately staffed with physicians, nurses and other personnel trained in emergency medicine.

In the early 1970s, the DOT developed the first National Standard Curriculum for EMT training. Supporting the national curriculum, the American Academy of Orthopaedic Surgeons (AAOS) published the first EMT textbook in 1971, *Emergency Care and Transportation of the Sick and Injured*. In the late 1970s to early 1980s the National Standard Curriculum was expanded to encompass paramedic training. By 1980, Emergency Medical Service was established throughout the nation. The system was based on two key features: 1) The responsibility of each municipality, township, or county to provide proper pre-hospital care and transport; and 2) the recognition of standards and regulations for training of emergency care technicians. Throughout the 1980s higher levels of care were added to the National Standard Curriculum in what is now known as Advance Life Support (ALS) and Basic Life Support (BLS) (Pollak, N. A., [3]).

2.1 Levels of Care

In most states of the Unites State of America, there are 2 different levels of care: Advanced Life Support (ALS) and Basic Life Support (BLS). Each emergency medical technician certification falls under one of the levels of care. An EMT-Basic (EMT-B) or First Responder will fall under BLS, while EMT-Intermediate (EMT-I) or EMT-Paramedic (EMT-P) will fall under ALS (Pollak, N. A., [3]). Not every state has all four levels of certification and some have very specific certifications. One such example is the EMT-Cardiac in the State of Rhode Island,

which specializes in dealing with cardiac related emergencies and the reading of a 12-lead electrocardiogram (EKG) (Lapierre, R. J., [4]).

First responders, as the name indicates, are usually the first people on scene who initiate care. Police officers, fire fighters, park rangers, ski patrollers and other rescuers are often first responder certified, if not EMT certified. They provide the immediate care to stabilize the patient and to pass him or her on to the next level of care. The next level of certification is the EMT-B, who has an extensive knowledge and training for providing basic emergency care in the field. They are trained to provide basic support to treat the patient in the field or to stabilize the patient for transport. Moving from BLS to ALS, the first level of certification is the EMT-I. An EMT-I has added ALS training to assist with paramedics and to better stabilize the patient. Some procedures an EMT-I is allowed to perform are IV therapy preparation, manual defibrillation, cardiac rhythm interpretation, and orotracheal intubation. At the paramedic level, it is almost like having the ER in the field. An EMT-P is capable of not only IV therapy, but also needle cricothyroidotomy, needle decompression for tension pneumothorax and many other medication therapies (Pollak, N. A., [3]). This diverse availability of care ensures efficient and proper provision for the patient (a list of levels of care and their respective certifications can be found in Appendix A).

2.2 Components of EMS

There are many components to the EMS system that are critical for successful provision of care. The first component of the system is access. Access to the system is essential for it to work, and much advancement to this has been made starting with the switch from the 9-1-1 system to the enhanced 9-1-1 system. Global positioning systems and cellular triangulation

systems have also been incorporated in to the 9-1-1 system to efficiently identify the caller's location to provide quick response to their needs. Next, medical direction and control is needed to provide effective care. Because EMTs are not doctors, they cannot diagnose or prescribe medication. They are not trained to diagnose a condition, and so they must rather treat the eminent condition and transfer care to the hospital where the patient will receive definitive care. Medical control allows for both online and offline consultation for EMTs to effectively provide care. Offline medical control is in the form of protocols specific to the local EMS system, while online medical control is a direct communication line to a physician medical director at a hospital who can give orders to be performed on his or her behalf. This is key, especially when the administration of a certain medication is indicated. However, an EMT must never provide care that is beyond their certification and has to remember his or her limitations (Pollak, N. A., [3]).

2.3 Potential Communicable Pathogens

As the initial step in patient care, pre-hospital care is vital for maintaining patient health and providing timely treatment. Due to their frequent use and insufficient time for sterilization between transports, ambulances are prone to contamination, and pose a significant risk for the patients and the emergency medical technicians (EMTs) on board. Among the ten most common symptoms in patients transported by an ambulance to emergency rooms, five involve the potential exposure to bodily fluids, which often carry multiple disease causing pathogens and can infect a healthcare personnel (Pollak, N. A., [3]).

Figure 1 – Personal Protective Equipment: Nitrile Gloves

A number of Personal Protective Equipment (PPEs), such as gowns, masks, goggles, booties, and gloves are available for use by EMTs for personal safety. Typically, the use of gloves and eye protection are mandatory, while other PPEs are only used at the technician's discretion. Figures 1 through 3 illustrate some simple PPEs that can be used to protect an EMT from potential communicable pathogens. A set of ambulance cleaning procedures are also used to maintain a sterile environment within an ambulance. Between calls and at the end of each shift, the inside of an ambulance is disinfected by spraying the surfaces with cleaning agent, wiping dry with a paper towel after 30 seconds, and repeating the steps in 10 minute intervals if necessary. Generally, PPEs that become bloody must be disposed in biohazard bags, and any visible bodily fluids within the ambulance must be thoroughly cleaned from surfaces and objects before disinfecting (Pollak, N. A., [3]).

Figure 2 - Personal Protective Equipment: Goggles

As mentioned earlier, Figure 1 through 3 illustrate some PPEs that are helpful in protecting an EMT from pathogens. Gloves and goggles (Figures 1 and 2) are effective at preventing direct contact to many bodily fluids. Masks (Figure 3) also provide protection against many airborne pathogens such as the common cold and even tuberculosis.

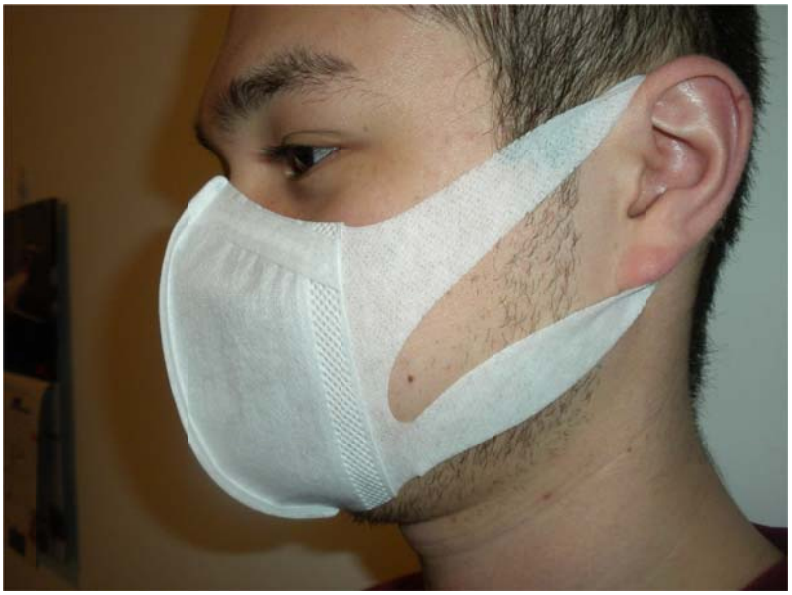


Figure 3 – Personal Protective Equipment: Disposable Mask

Prevention is important, especially through the use of PPEs, however EMTs will greatly benefit from installations of pathogen detection systems in each ambulance. Such systems will provide quick identification of pathogens and help with selection of appropriate PPEs and decontamination procedures after calls. Enzyme Linked Immuno Sorbent Assays (ELISA) are currently available on the market for both home and laboratory use in the form of either a urine dipstick or 96-well plates. An example of a commonly used ELISA for non-laboratory use is the pregnancy test. ELISAs are a biochemical technique that is highly efficient in detecting the presence of an antibody or an antigen in a given sample. Because of the specificity of ELISAs toward an antigen, multiple ELISAs would need to be carried out to detect the presence of common pathogens. ELISA is also a time consuming technique that requires extensive preparation (Crowther, R. J, [2]). Based on similar principles of ELISA, automated biosensors detect disease antigens or antibodies without the manual labor required for ELISA.

2.3.1 Modes of Transmission

The first area to explore in contaminant identification involves transmission types as they pertain to the ambulance. There are many different types of transmission, but for the purposes of the project the types investigated were Direct, Indirect, Airborne, and Droplet. Protection against every mode of transmission varies from simple to heavy-duty PPEs. Simple PPEs are often enough to protect the health care worker from many pathogens, but depending on the severity of the pathogens, a higher class PPE may be necessary like the one shown in Figure 4.

Figure 4 – Personal Protective Equipment: Hazmat Suit

The PPE shown here is a Class A Hazmat suit lacking a respirator. Such protection is required for infectious agents with high pathogenicity. Class A Hazmat suits can provide a complete isolation from the surrounding environment.

Direct transmission involves direct contact with an infected person. This generally involves mouth-to-mouth contact, sexual intercourse, and most relevant to the ambulance setting: simple physical contact. Indirect transmission is also a form of contact transmission wherein infection occurs through contact with contaminated objects, known as fomites. Fomites can include various surfaces, although they typically do not include food, air, or liquids. Indirect transmission is harder to avoid than direct transmission, although certain pathogens require a specific level of durability in order to survive on fomites. Airborne transmission entails transmission of contaminants through the air. This typically involves aerosols (very small droplets) or dust particles being responsible for infection. Pathogens that are transmitted via airborne transmission typically require even more organismal durability because the time spent

before infecting a new host is longer. Droplet transmission is a form of contact transmission and is similar to airborne transmission, but it occurs at closer range and thus, more quickly. The general rule of thumb for droplet transmission is that the transmission must occur within one meter from the mouth after exit, otherwise it is considered to be airborne transmission. Typically, this entails being sneezed, spit, or coughed on (Pollak, N. A., [3]).

2.3.2 Bloodborne Pathogens

Of the pathogenic risks present for healthcare professionals, bloodborne pathogens are the most prominent and serious of contaminants. To list all bloodborne pathogens would be excessive; therefore the most common and high risk probable pathogens were selected and researched. The first category of most common pathogens includes Human Immunodeficiency Virus (HIV), which may lead to Acquired Immune Deficiency Syndrome (AIDS), Hepatitis B Virus (HBV), Hepatitis C Virus (HCV), and Hepatitis D Virus (HDV). The latter category of high risk pathogens includes Malaria, West Nile Virus, Viral Hemorrhagic Fevers (Ebola and Lassa). Although they are not common, they may be of serious concern due to efficient travel methods, notably air travel, and over use of antibiotics.

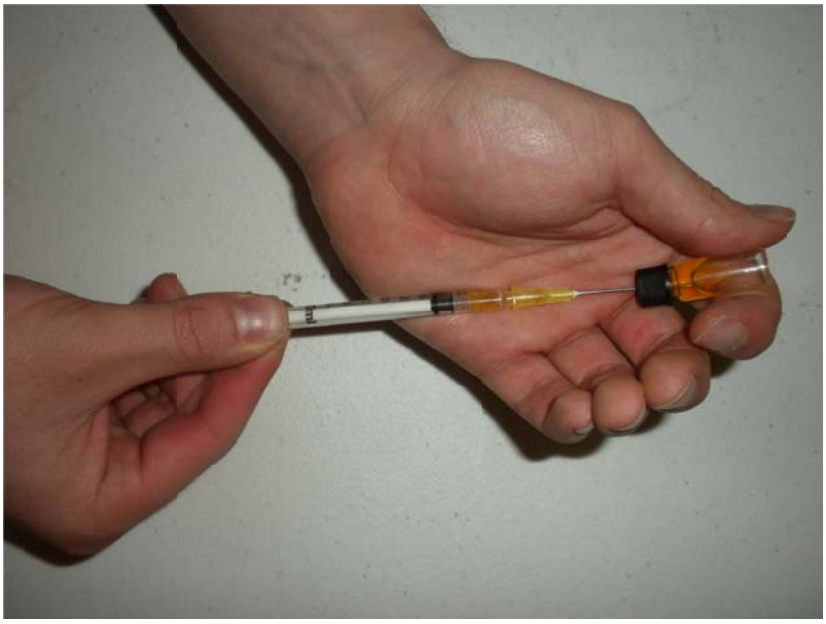


Figure 5 – Hypodermic Needle

As Figure 5 illustrates, the use of needles, especially amongst drug users, raises concerns of bloodborne pathogens for healthcare workers. The first of the most common pathogens that were researched was HIV/AIDS. HIV is a major public health concern; it is estimated that approximately 1,106,400 people are infected in the United States. Within that population, approximately 20% are estimated to be unaware of their infection. HIV infection rates are markedly increasing in certain areas of the United States. For example, 1 in 30 adults in Washington, D.C are HIV-infected, which is much higher than in Ethiopia, Nigeria or Rwanda. In New York City alone, 1 in 40 African Americans, 1 in 10 men who have sex with men, and 1 in 8 drug users (via injection) are HIV-infected (Katz, I. T., and Landovits, R J., [7, 6]). EMTs working in such areas are exposed to high risks of contamination through accidental needle pricks or blood splashes. EMTs are recommended to follow body substance isolation precautions and wear proper personal protective equipment when appropriate (Pollak, N. A., [3]). Even with such care, exposure may be unavoidable and postexposure prophylaxis must be

activated immediately. Such treatment may take as long as 28 weeks and have a follow up period of up to 6 months. Nevertheless, postexposure prophylaxis has an 81% likelihood for patients to remain with HIV-negative serum. Healthcare personnel exposed to bodily fluids from their patients are indicated to go through postexposure prophylaxis if the patient is known to be HIV-positive with a high viral load, if the patient is known to be HIV-positive with a low viral load, or if the HIV seroconversion status is unknown. However, even if postexposure prophylaxis is indicative, it is a huge mental and physical burden on the victim and reported rates of adherence to medication are generally in the range of 70% to 80%. Much of the drugs used have side effects including, but not limited to, potential nephrotoxicity, nausea, asthenia, neutropenia, anemia, abnormal liver-enzyme levels, diarrhea and other gastrointestinal side effects. Patients going through postexposure prophylaxis should have their medical condition, especially hepatic condition monitored. HIV testing is indicated throughout the treatment and also during a follow-up (Landovits, R. J., [7]).

Chronic viral hepatitis was researched next. HBV is the second most common cause of acute viral hepatitis after HCV. HBV risks are greatly increased with healthcare personnel who may be in contact with blood. There are approximately 1.2 million carriers in the United States. Many hospitals and ambulance services require that their employees be vaccinated for HBV. When exposure to the virus is suspected, immediate testing using rapid Enzyme-Linked Immunosorbent Assay for Hepatitis B surface antigen (HBsAg) is indicated along with postexposure prophylaxes. HCV is the most prominent with about 3.2 million carriers in the United States. There are several major HCV subtypes found in varying geographic locations that differ in virulence and response to therapy. They also have the ability to alter their amino acid

sequences over time in an infected patient, hindering with effective therapy responses (Albert, R. K., and Shapiro, C. N., and Hoofnagle, J. H., [5, 8, 9])

Figure 6 – Sharps Disposal

The mentioned bloodborne pathogens all have the potential of being transmitted though accidental needle pricks from hypodermic needles used by drug users, or from improperly disposed needles used by a healthcare worker. Proper disposal of hypodermic syringes, as illustrated in Figure 6, is important in preventing infection by many bloodborne pathogens (Pollak, N. A., [3]).

Although the main bloodborne pathogens that are typically worried about are HIV/AIDS, HBV, HCV, and HDV, there are also other risks. Some of these 'secondary' bloodborne

pathogens include West Nile Virus and malaria. These diseases are typically transmitted through mosquito bites, however, one might also contact these diseases through blood transfusions or needle pricks (Pealer, L. M. [10]). For West Nile Virus, there were a total of 547 cases reported in the United States during 2010, with 22 deaths, according to the CDC. Oftentimes, there are no symptoms exhibited, although in some cases, patients present with cold or flu-like symptoms such as mild fever, headache, and chills. Detection for West Nile Virus is done by polymerase chain-reaction assay (Pealer, L. M., [10]), and in order to prevent the disease, it is best to take anti-mosquito measures and to be cautious around infected individuals. For those infected with West Nile Virus, there is no vaccine or direct treatment available, and so general supportive care is usually given.

Malaria is a more serious disease, and although it has been for the most part eradicated in the United States, it is a serious problem in many other countries. On average, only 1500 cases are reported in the United States (Freedman, D. O., [11]). In infected individuals, the disease can attack the liver and if left untreated, can be fatal (Okie, S., [12]). The symptoms for malaria are chills, fever, sweating, nausea, vomiting, and diarrhea. As the disease attacks the liver, symptoms such as jaundice and anemia can also be present (Freedman, D. O., [11]). In order to test for the disease, a blood test is often conducted to observe the presence of the malaria parasite. There is no vaccine to prevent the disease, although anti-mosquito measures and anti-malaria drugs are effective (Okie, S., [12]). To safeguard medical workers working with malaria patients, Universal Precautions by OSHA should be observed.

Another type of bloodborne pathogen that can be dangerous for medical workers is those among the Viral Hemorrhagic Fevers (VHFs). Although not all VHFs can be transmitted by contact with blood, two serious diseases that can be transmitted this way are the Ebola and Lassa

Viruses. These diseases are quite uncommon, but some research has been dedicated to them due to the fear that they might be used as biological weapons. The Ebola Virus falls under the filoviridae family of VHFs, and has been known to infect humans and non-human primates. There have been no reported cases in the United States; however, there have been serious sporadic outbreaks on the African continent. This disease can be acquired through both Direct and Indirect Transmission. The symptoms for Ebola are fever, headache, muscle and joint pains, sore throat, weakness, vomiting, diarrhea, and stomach pains. In some patients, rash, red eyes, and internal and external bleeding is present (Albert, R. K., [5]). In order to test for the Ebola Virus, ELISAs and Polymerase Chain Reaction (PCR) tests can be performed. Because so little is known about this virus, there are no vaccines or direct treatments. Supportive care involving balance of the patient's fluids and electrolytes and responding to complications that arise from internal and external bleeding is all that can done. For medical workers, use of Personal Protective Equipment (PPE) is strongly advised, along with avoidance of direct contact with the infected person if possible (Peters, C. J., [13]).

The Lassa Virus falls under the Arenaviridae family of VHFs. It is estimated that there are 100,000 to 300,000 infected individuals in West Africa. Although the virus' natural carrier is the *Mastomys* rodent, this disease can also be transmitted through Direct or Indirect transmission. Patients with Lassa Virus may exhibit fever, retrosternal pain (pain behind the chest wall), sore throat, back pain, cough, abdominal pain, vomiting, diarrhea, conjunctivitis, facial swelling, proteinuria (protein in the urine), and mucosal bleeding. In addition, certain neurological problems may be present (Albert, R. K., [5]). Testing for Lassa Virus typically entails use of ELISAs or RT-PCR. Like the Ebola Virus, there is no vaccine or direct treatment, although antiviral drugs such as Ribavirin can be used along with supportive care. Lassa Virus prevention

often involves taking anti-rodent measures, and for medical workers working with infected patients, use of PPEs are strongly advised (Pollak, N. A., [3]).

2.3.3 Airborne Pathogens

Airborne pathogens cannot be visualized like many bloodborne pathogens, and can therefore be harder to protect against. Common airborne pathogens mentioned in EMT textbooks are *Mycobacterium tuberculosis*, chickenpox, *Histoplasma, Coccidioides, Mycobacterium avium-intracellulare* and influenza (Pollak, N. A., [3]). These pathogens are transmitted either by droplet nuclei from the patients mouth or by dust carried in the environment in which the patient or the technician is exposed to.

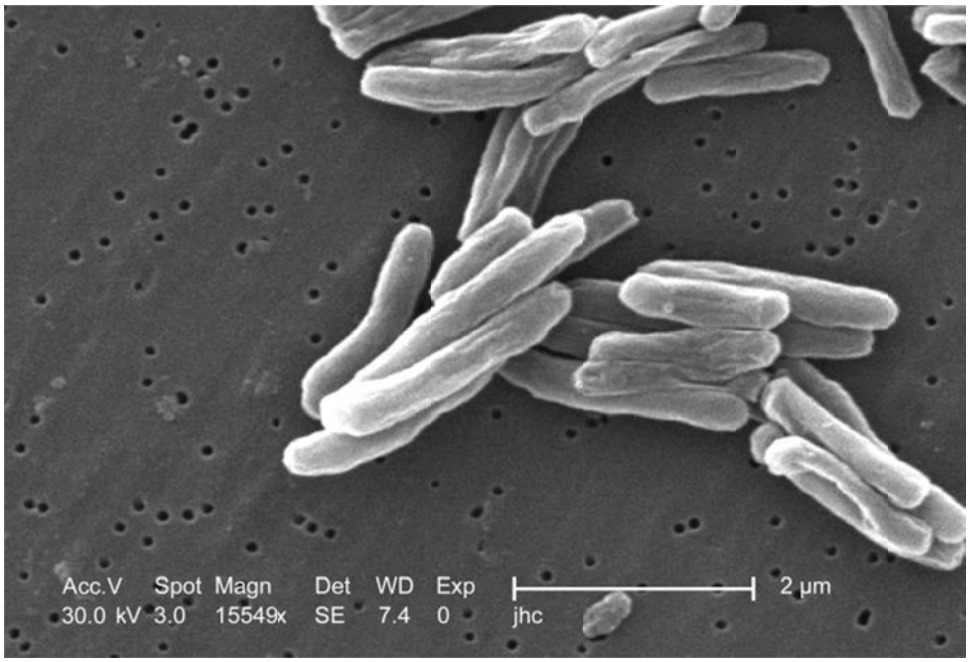


Figure 7 - Electron micrograph of *Mycobacterium tuberculosis* [52]

The well-known Tuberculosis (TB) is caused by an airborne pathogen called *Mycobacterium tuberculosis* (Figure 7). TB infects the lungs, proliferating in phagocytes and causing coughs, fatigue, fever and weight loss in many patients (Murphy, K., and Travers, P., [14]). It requires immediate treatment with antibiotics and is often very contagious. Droplets that contain TB can

remain viable for a long time increasing the probability of infection (Pollak, N. A., [3]). However careless and extensive use of antibiotics has led to Multi-Drug-Resistant TB (MDR TB), which is a pressing problem in many countries worldwide (Keshavjee, S., [15]).

Table 1 - The Prevalence of Latent Tuberculosis Infection

Group	Expected Prevalence % (95% CI)
Foreign-born persons	18.7
Close contacts of persons with infectious tuberculosis	37.1
Homeless persons	22.6
Injection-drug users	20.1
Prisonsers	9.4

Table 1 illustrates the percent prevalence of residents in the Unites States that have latent tuberculosis. Latent tuberculosis has the potential of progressing from latent active disease, thus placing others at risk for contracting the disease. More than 80% of tuberculosis cases in the U.S. are the result of latent TB infection progressing to the full disease. Unfortunately, there is no way to detect the presence of latent TB in any individual patient and a detailed medical history along with skin test results must be interpreted to compute the probability of latent TB. A new diagnostic testing method for latent tuberculosis has recently come on the market and has potential for effective detection of latent TB. QuantiFERON-TB Gold and T-SPOT.TB tests are both interferon-γ-release assays (IGRAs) and measure interferon-γ levels secreted from cells in vitro. Cells obtained from the patient are exposed to purified protein derivatives (PPD) from *M. tuberculosis* and interferon-γ secretion from sensitized lymphocytes are monitored (Horsburgh, R. C., and Rubin E. R., [16]).

Table 2 – Prevalence of Latent Tuberculosis Progression to Active Disease

Risk Factor	Relative Risk % (95% CI)
Advanced, untreated HIV infection	9.7
Close contact with a person with infection tuberculosis	6.1
Radiographic evidence of old, healed tuberculosis that was not treated	5.2
Treatment with ≥15 mg of prednisone per day	2.8
Chronic renal failure	2.4
Treatment with TNF-α inhibitor	2.0
Poorly controlled diabetes	1.7
Weight ≥10% below normal	1.6
Smoking	1.5

Table 2 demonstrates the relative risks of latent TB progressing in to the active disease for each population group. The top three risk groups are patients who have advanced, untreated HIV, patients who have had close contact with a person infected with TB or a patient who had radiographic evidence of old, healed TB that was not treated.

Chickenpox is caused by the varicella-zoster family of viruses, and seems benign for children, but can be serious for adults. It causes rashes and fever, which in many patients can range from mild to severe. Influenza, also known as the flu, is widely prevalent. It often presents as a severe cold with headaches, joint pain, fever, sore throat and even nausea (Albert, R. K., [5]). If overlooked, the condition can worsen rapidly and possibly even lead to death.

Although influenza is contagious through coughing, a simple mask can often times prevent transmission (Pollak, N. A., [3]). Figure 8 illustrates the cough plumes dispersing around the patients rather than moving forward when wearing either a standard surgical mask or an N95 respirator (Tang, J. W., [17]).

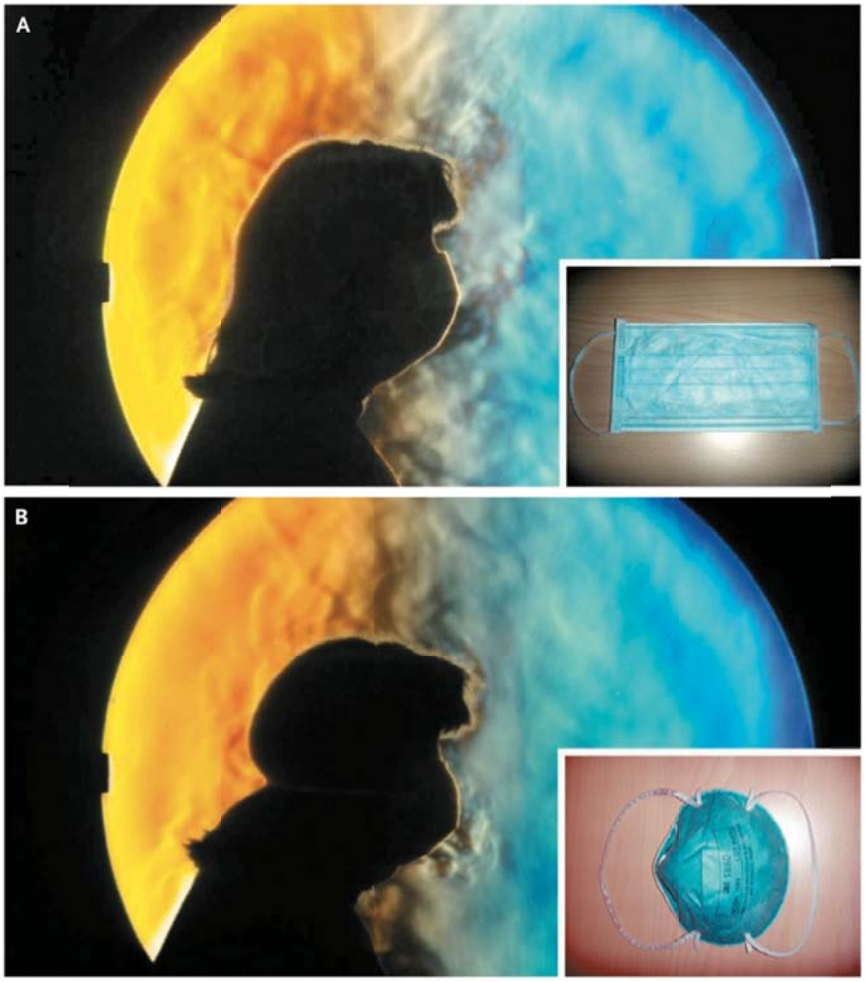


Figure 8 - Schlieren Optics of Cough Plume

The use of a mask can prevent the transmission of pathogens. Schlieren optics can show the dispersal of expelled air when a patient coughs. Panel A shows a patient coughing with a standard surgical mask. Panel B shows a patient coughing in a N95 mask. The plumes observed

from either masks shows enhanced barrier that prevents the forward movement of the coughs, which could travel 1 to 2 meters if not wearing one (Tang, J. W. and Settles, G. [17]).

2.3.4 Other Pathogens

The pathogens mentioned thus far are not the only types that pose a threat to those working in emergency medicine. The mode of transmission for these are either direct or indirect contact and of most concern within the healthcare industries are Methicillin-resistant *Staphylococcus aureus* (MRSA), Vancomycin-resistant *S. aureus* (VRSA), and *Clostridium difficile* (CDF). These pathogens are often times transmitted through bed sheets of hospitals, however since ambulances use sheet-like material for their stretchers, it still possesses potential for contamination and transmission. Intravascular catheters are also a common location of *S. aureus* infection. Skin infections of *S. aureus*, MRSA and VRSA are the most common form of the disease. In a hospital situation, such cases are dealt by either disinfecting the contaminated objects or replacing them. Patients are treated with antibiotics as illustrated in the Table 3 (Albert, R. K., [5]).

Table 3 – Treatments for patients infected with *S. aureus.*

Infection	Drugs
Community-acquired cutaneous infections (non-MRSA)	Dicloxacillin or cephalexin 250-500mg po q 6 h for 7-10 days
Penicillin-allergic patients with Community-acquired cutaneous infections (non-MRSA)	Erythromycin 250-500mg po q 6 h; clarithromycin 500mg po q 12 h; azithromycin 500mg po on the 1st day then 250mg po q 24 h or clindamycin 300 mg po q 8 h
Serious infections that are unlikely to be MRSA	Nafcillin or oxacillin 1-2 g IV q 4-6 h or cefazolin 1 g IV q 8 h
Penicillin-allergic patients with Serious infections that are unlikely to be MRSA	Clindamycin 600 mg IV q 8 h or vancomycin 15mg/kg q 12 h
Serious infections with high likelihood of being MRSA	Vancomycin 15 mg/kg IV q 12 h or linezolid 600 mg IV q 12 h
Documented MRSA	By reported sensitivities
Vancomycin-resistant staphylococci (*Note: no clinical data, but listed drugs appear to be active in vitro – doses not established)*	Linezolid 600 mg IV q 12 h; quinupristin plus dalfopristin 7.5 mg/kg q 8 h; daptomycin 4 mg/kg q 24 h

Treatment for MRSA, or VRSA depends on the patients condition and seriousness of infections. The first two rows (non-MRSA) of Table 3 illustrate the use of oral antibiotics rather than IV antibiotic therapy, as is the case for the remaining rows – MRSA or VRSA infections.

2.4 Documented Occupational Exposures

Although one large motivator for this project has been to reduce the time needed to clean and decontaminate the ambulance, another significant reason for the project has been to try and reduce instances of occupational exposure to pathogens. Occupational exposure in the ambulance setting can occur through exposure to bodily fluids or from inhalation of pathogens from the patient. Typically, exposure of bodily fluids is characterized by "percutaneous injury caused by a contaminated needle or other sharp object, contact with mucous membranes or non-intact skin, or contact with intact skin when involving extensive areas for a long period of time" (Marino, C. G. G., [18]).

Table 4 - Reported Exposures to Bloodborne Viruses among Healthcare Workers.

	Percutaneous	Mucotaneous	Bites/Scratches/ Unknown	No. of Incidents
Nurses/Midwives	210	82	16	308
Doctors	200	41	14	255
Healthcare Assistants	20	5	4	29
Laboratory Workers	9	5	0	14
Dentists	11	0	0	11
Phlebotomists	8	1	0	9
Dental Hygienists/Nurses	5	0	3	8
Paramedics	**2**	**3**	**1**	**6**
Radiographers	2	3	1	6
Operating Department/Theater Assistants	4	1	0	5
Technicians	5	0	0	5
Porters	1	3	1	5
Others	6	7	4	17
Not Known	85	35	15	135

Table 4 was constructed using 813 reports of health care workers in the United Kingdom. Although the majority of health care workers that become exposed to contaminated bodily fluids typically work in the hospital setting, the recorded instances of paramedics being exposed to bloodborne viruses are not insignificant (Evans, B., [19]). It is interesting to note, however, that some observers note that many accidents involving exposure "often happen during cases of emergency". As one hospital room emergency doctor describes from a past personal experience, "It was so urgent, the blood was spewing, what can you do? You can only stop the bleeding immediately" (Lin, C., [20]). Although that particular doctor worked at a Chinese hospital, many health care workers around the world potentially have the misfortune to be put in the same

situation. Ambulance workers deal with emergencies quite often, so the risk of exposure that comes with immediately responding to an emergency is ever present.

The majority of the studies conducted on health care workers and occupational exposure have involved the three bloodborne pathogens that pose the greatest risk: Hepatitis B, Hepatitis C, and Human Immunodeficiency Virus (HIV). Although exposure to these contaminants can happen through any of the several methods listed previously, the majority of instances of occupational exposure to bloodborne pathogens are through "percutaneous injury with a sharp object", such as a needle or a lancet (Rapiti, E., [21]).

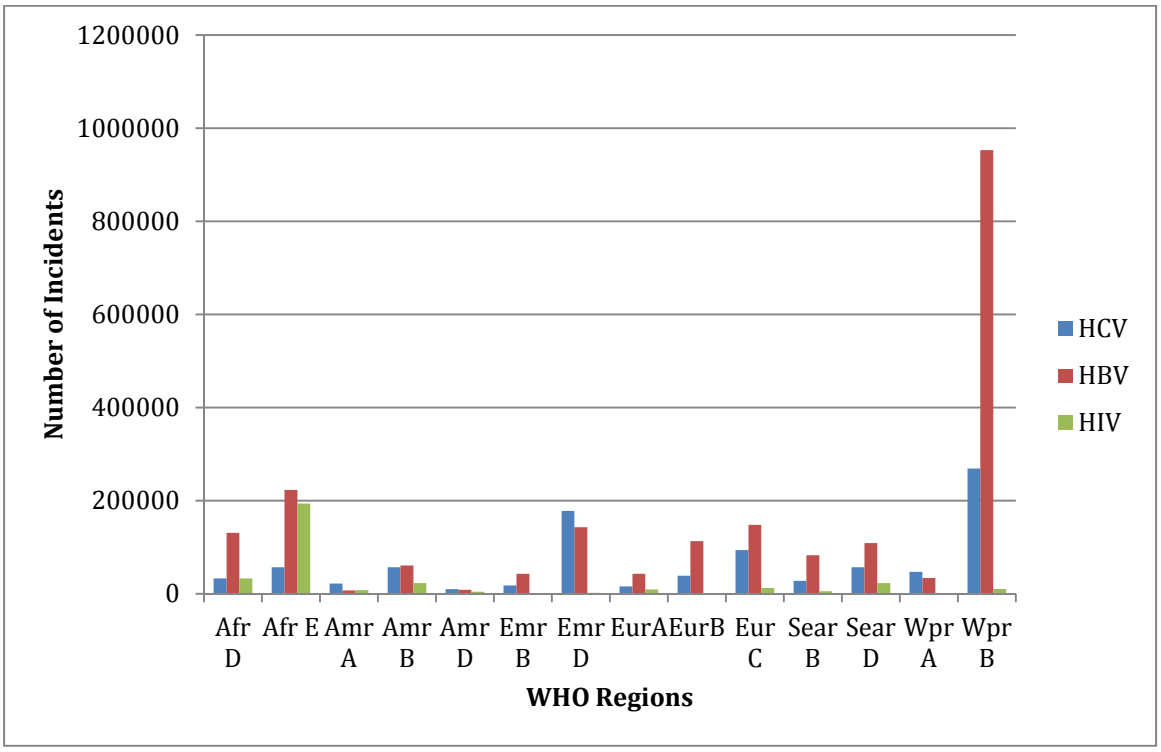


Figure 9 – Reported Incidents of Percutaneous Injury with a Contaminated Sharp Object

In a document produced by the World Health Organization (WHO), studies were conducted to evaluate the toll of HBV, HCV, and HIV on a global level. Part of this evaluation involved using data from countries within the 14 WHO regions as listed in Figure 9. This figure details the

number of health care workers who become exposed to one or more percutaneous injury with a sharp object (Rapiti, E., [21]).

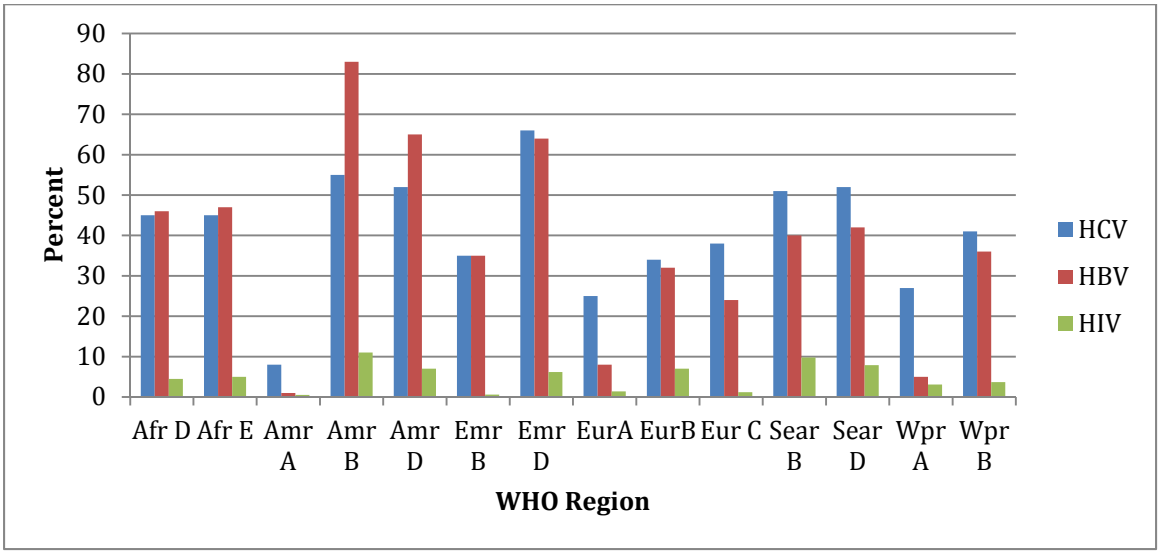


Figure 10 – Percentages of Infections among Healthcare Workers

In the same WHO document, they had modeled and provided an estimate of the percentage of infections in health care workers by HBV, HCV, and HIV. One point in Figure 10 that might be of interest is Amr A, the region in which the United States is classified (Rapiti, E., [21]).

Other pieces of literature that deal with the same subject have produced similar results, with only some variation, partially due to the fact that the risk is dependent on whether the contamination is "e" antigen positive or negative. For HBV, the risk of acquiring HBV from percutaneous injury has been listed as ranging from 6 to 30% (Marino, C. G. G., [18]) or even as high as 40% (Varghese, G. M., [22]). In the case of HCV, the risk is a bit lower, being listed as between 3 and 10% (Marino, C. G. G., [18]), 0 and 7% (Varghese, G. M., [22]) or 1.2 and 10% (Sadoh, W. E., [23]). For HIV, the risk seems to be more consistent between literature sources, described as being 0.3% through percutaneous injury, or 0.09% after mucous membrane exposure (Marino, C. G. G., and Vargese, G. M., [18, 22]).

Table 5 - Post-exposure HIV Infection Risk

	Adjusted Odds Ratio
Deep Injury	16.1
Visible Blood on Device	5.2
Procedure Involved Needle Placed Directly in Blood or Artery	5.1
Terminal Illness in Source Patient	6.4
Postexposure use of Zidovudine	0.2

One literature source investigated other factors that might affect the risk of HIV infection in health care workers exposed to infected blood, discussing factors such as deep injury to the health care worker, terminal illness in the patient, or post-exposure use of zidovudine, a type of antiretroviral drug. As can be seen in the Table 5, deep injury has great effect on the risk of becoming infected with HIV (Johnson, D. C., [24]).

Although airborne pathogens do not present as great a risk in occupational exposure, there is still some literature to suggest that precautions should still be taken. One article, describing the prevalence of H1N1 among hospital staff at a hospital in Singapore listed that among 531 participants in the study, 35 showed evidence of seroconversion, most of whom were nurses "posted to designated pandemic (H1N1) 2009 isolation wards" (Chen, M., [25]). This result suggests that any health care worker who spends a significant amount of time around an infected individual runs a higher risk of contracting the disease themselves. If proper precautionary measures are not taken, as in low to middle income nations, risk of contracting airborne pathogens may be significant, as mentioned in another article detailing the incidence and prevalence of latent tuberculosis infection (LTBI) among health care workers. By collecting data from nations such as India, Mexico, Thailand, South Africa, and others, it was demonstrated that estimates of the annual risk of contracting LTBI ranged from 0.5 to 14.3% (Joshi, R., [26]).

2.5 Cleaning Agents

In addition to emphasizing the importance of consistent and effective cleaning in disinfecting procedures, the United States Environmental Protection Agency has categorized antimicrobial agents for cleaning different types of contamination (Environment Protection Agency, [27]). With a wide selection on the market, cleaning agents differ greatly in their cost and intended use. Antiseptics and disinfectants are used extensively in health care settings for a variety of applications. In hospitals, they are used mainly for preventing disease transmission and aiding infection control. The general recommendation for cleaning under any health care related setting is that cleaning should occur from the cleanest area to the dirtiest (McDonnel, G., and Russell, A., [28]). In the general public, the recent growing attention to disinfection has led to increased use of antiseptics and disinfectants in household cleaning products. A wide variety of active chemical agents, also called biocides, can be found in these popular products. A biocide is a term describing a chemical agent of any nature that inactivates microorganisms. Ranging in antimicrobial activity, biocides differ in the way they kill germs. Unfortunately, the recent widespread use of antiseptic and disinfectant products has raised serious speculation on the development of microbial resistance, especially cross-resistance to antibiotics (McDonnel, G., and Russell, A., [28]). Therefore, it is crucial for healthcare workers to choose the correct cleaning agents for both maximum effectiveness and minimum microbial resistance.

Under healthcare settings, contamination is commonly defined as the soiling or pollution of inanimate or living material with harmful and potentially infectious substances. These contaminations may be transferred to a susceptible target if not decontaminated properly and timely. Decontamination is defined as a series of processes that removes or inactivates contamination, preventing sufficient quantities of microorganisms or other harmful substances

from spreading. The process of decontamination is composed of a number of steps, including cleaning, disinfection, and/or sterilization. The series of decontamination procedures allow for safe usage of reusable medical equipment and instruments. As the first level of decontamination, cleaning is the process of removing any visible contamination from surfaces. It must be conducted before disinfection and sterilization. For certain low-risk items, cleaning may be all that is required before they are deemed reusable. Usually achieved through the use of chemicals such as disinfectants, disinfection is the second step of decontamination that reduces the number of viable microorganisms, but it is not entirely effective against bacterial spores or some viruses. Disinfection is generally sufficient for medium-risk items, which do not come into contact with a break in the skin or mucous membranes. Sterilization is a decontamination process in which all microorganisms, including spores and viruses are destroyed. Most often achieved by high pressure and temperature steam, sterilization is much more time consuming, costly, and impractical when compared to disinfection. Thus, it is only used for high-risk items (United Kingdom National Health Service, [29]).

Table 6 - Recommended Disinfectants

Disinfectants		
Type	**Example**	**Comments**
Chlorine Dioxide	Tristel	Endoscope disinfection
Sodium Hypochlorite	Titan Sanitiser	Spillages of blood/body substances – wards/departments
Alcohol 70%	Hand gel	For use on physically clean hands – refer to hand hygiene guidelines
	Alcohol solution	Skin preparation – not to be used for soaking items of equipment
	Cliniwipes/mediwipes Mediswabs	Skin preparation wipes may be used for smooth, clean surfaces or equipment that cannot be immersed in solutions
Chlorhexidine	Hibitaine	Skin preparation/surgical scrub Not necessary for routine hand washing – liquid soap adequate
Iodine	Betadine Disadine Videne	Skin preparation Hand disinfection

A number of disinfectants and antiseptics that are recommended for disinfecting surfaces and skin are listed in Table 6. Chlorine dioxide, commonly found in Tristel, is highly effective for the disinfection of various types of endoscopes. Sodium hypochlorite found in Titan sanitizer, is great for neutralizing spillages of blood and other body substances and fluids. 70% alcohol is widely used in hand gels, alcohol wipes and swabs, is effective for disinfecting cleaned surfaces or equipment that cannot be soaked in solutions. It is also useful in skin preparation. To ensure effectiveness, alcohol should always be allowed to evaporate from disinfecting surfaces before further usage. Other antiseptics effective in the disinfection of skin

include chlorhexidine and iodine, commonly found in products such as Hibitaine, Betadine, Disadine, and Videne (United Kingdom National Health Service, [29]).

Table 7 – Effectiveness of Hand-Washing

Treatment Group	No. of hands Positive / No. of Candidates Tested
Unwashed Hands	16/16
Water	14/16
Water + Soap	11/16
1.5 ml 65% Ethanol	2/15
1.5 ml 65% Ethanol × 2	3/16
1.5 ml 83% Ethanol	3/16

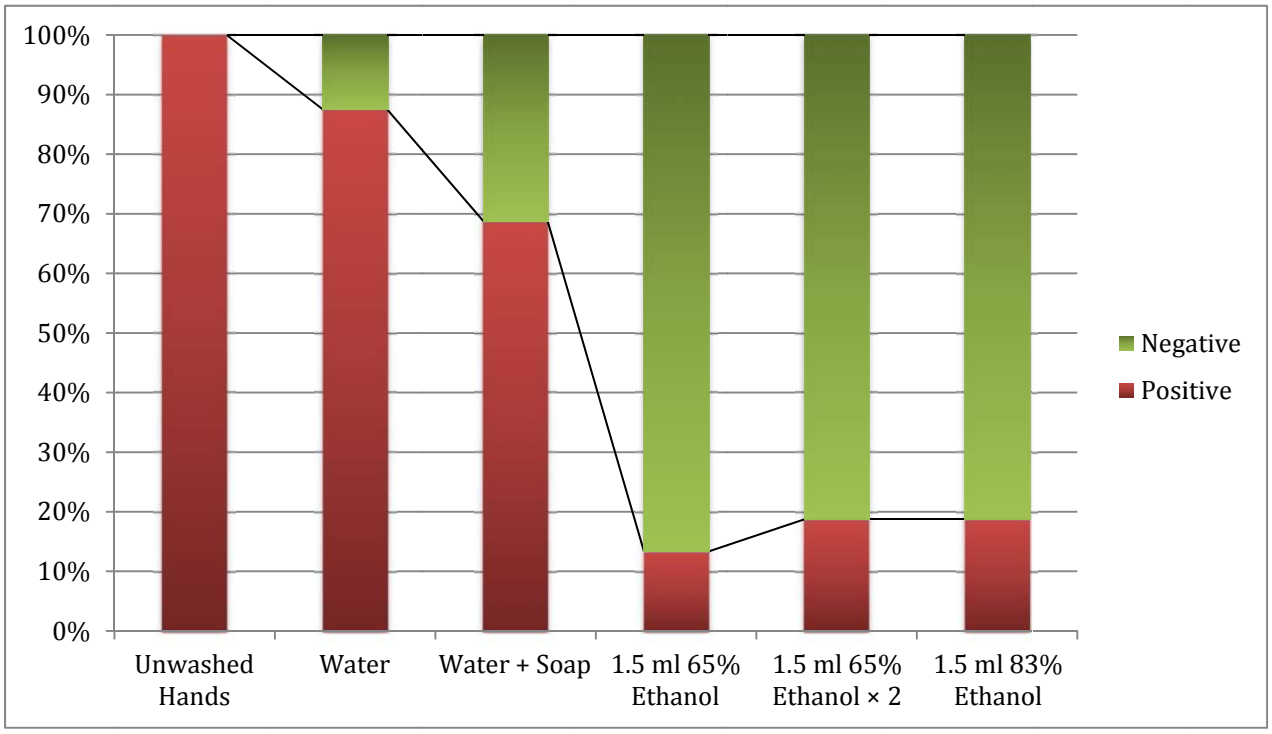


Figure 11 – Graphical Representation of Effectiveness of Hand-Washing

Studies conducted at the University of Virginia School of Medicine evaluated the effectiveness of ethanol hand sanitizers with or without organic acids to removed rhinovirus from hands and prevent future virus recovery (Turner R., B., et al., [30]). The results of the study are shown in Table 7 and Figure 11. Fingers of 95 volunteers were contaminated with

doses of rhinovirus. The subjects were randomly distributed into six hand treatment groups. A control group received no treatment. A second group washed their hands under running water for 15 seconds. Another group washed their hands with non-medicated liquid soap and water for 15 seconds. A fourth group received 1.5 milliliter of 65% ethanol hand sanitizer to apply on the hands. A fifth group received 3 milliliter of 65% ethanol hand sanitizer for two adjacent applications. The final group applied 3 milliliter of 83% ethanol hand sanitizer in one application. After the various hand treatments, all volunteers had their fingertips screened for residual virus. As shown in Table 7, all ethanol treatments were significantly more effective than no treatment, water alone, or soap and water for removing rhinovirus from the hands. As demonstrated in Figure 11, water alone only removed detectable virus from 13% of the 16 hands, while water and soap removed 31% from the individuals (Turner, R. B., et al., [30]). The study also showed that no visible cleaning improvements can be observed from using more volume or more concentrated ethanol hand sanitizers.

Table 8 – Effectiveness of Hand Sanitizers with Organic Acid Additives

Parameter	Results for Group:		
	Control (2 hr)	Organic acid treated	
		2 hr	4 hr
No. of hands positive / no. tested	57/61	1/61	0/60

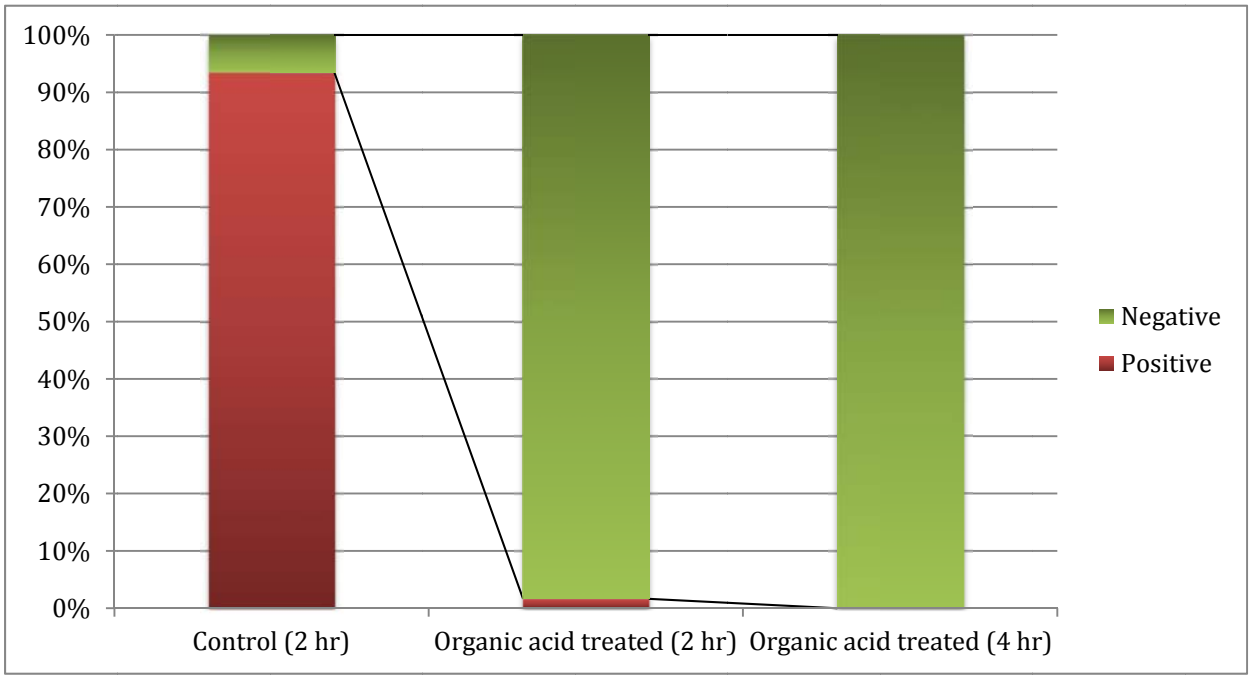


Figure 12 – Graphical Representation of Effectiveness of Hand Sanitizers with Additives

Another experiment was conducted by the same researchers to evaluated whether adding organic acids in ethanol hand sanitizer would provide antiviral activity that would persist for some period of time after application of the sanitizer. These results are shown in Table 8 and Figure 12. The study involved 197 healthy volunteers, and used an organic acid test product containing 2% malic acid and 2% citric acid in a 70% solution of ethanol (Turner, R. B., et al., [30]). A 65% Purell ethanol hand sanitizer was used for the control. The subjects were randomly distributed into three treatment groups. Two groups received the organic acid treatment, while one group received the control treatment. After application, the control group and one of the organic acid treated group waited 2 hours before exposure to the virus, and the

other organic acid treated group waited 4 hours before similar exposure. After allowing the virus to dry on the hands for 10 minutes, the fingers of the volunteers were screened for viable rhinovirus. As shown in Table 8 and Figure 12, the organic acid hand treatment had residual activity that inactivated the virus on the hands 2 and 4 hours after application. The study demonstrated the importance of using appropriate disinfectant and antiseptics, especially for emergency responders that frequently come in contact with pathogenic contaminants (Turner, R. B., et al., [30]). Not only can ethanol hand sanitizers effectively remove viruses from the hands, ethanol-based sanitizers containing formulated organic acids are also capable of significantly reducing virus recovery from the hands for up to 4 hours after application.

2.5.1 Current Ambulance Cleaning Methods

As vehicles used for providing emergency medical care, ambulances carry patients with various kinds of diseases and illnesses. In order to prevent cross contamination and infection within an ambulance setting, staff have a responsibility to keep the vehicle clean. Otherwise, those same vehicles can become a haven for pathogens. Research has shown that ambulances are potentially the weakest link in the fight against diseases such as MRSA and other superbugs. This is partly because ambulance crews do not always have the time to thoroughly clean and disinfect the interior of the vehicles between emergency calls (BBC News, [31]).

In order to keep ambulances clean and to reduce improper cleaning techniques, the U.S. Department of Health & Human Services proposed a series of guidelines for cleaning EMS transport vehicles. The published governmental guidance recommends that EMS agencies consistently practice basic infection control procedures, and properly use Food and Drug Administration-regulated medical personal protective equipment. The guidelines also stressed

the importance of extra precaution during influenza seasons (United States Department of Health and Human Services, [32]).

The basic components of effective contaminant control include routine cleaning of the patient loading area with soap or mixture of detergent and water to remove soil and organic matter, followed by the use of disinfectants. To ensure reusability of ambulance equipment, equipment should be covered with disposable covers to protect them from contamination if they cannot be properly decontaminated with disinfectant without causing damage to the hardware. The covers should be routinely changed or whenever visibly contaminated. The routine cleaning method should be implemented throughout the interior of the ambulance, especially in certain hard-to-clean areas as listed below (BBC News, Unites States Department of Health and Human Services, [31, 32]):

1. EMS agencies should clean and disinfect non-patient-care areas of an ambulance such as the driver's compartment according to the vehicle manufacturer's recommendations. These areas of the vehicle may become unintentionally contaminated by the ambulance staff touching the steering wheel with a contaminated glove.
2. Ambulance staff should wear non-sterile, disposable gloves that are compatible with the types of detergent and disinfectant used while handling the cleaning solutions and when cleaning the ambulance surfaces. Used gloves should be disposed in a sturdy leak-proof bag if they become damaged, soiled, or after cleaning is complete. Used gloves should never be washed or reused. All personnel should avoid activities that may generate infectious aerosols while cleaning the interior of an ambulance, and the staff should wear eye protection such as a face shield or goggles if splashing is expected.

3. Frequently contaminated surfaces in patient-care compartments are identified including stretchers, railings, medical equipment control panels, adjacent flooring, walls, ceilings, work surfaces, door handles, radios, keyboards, and cell phones. These surfaces can be directly contaminated with respiratory secretions, aerosols, and other bodily fluids during patient care, or indirectly contaminated by touching the surfaces with gloved hands. Periodically, these areas should be cleaned with detergent and water, and then disinfected using an EPA-registered hospital disinfectant according to its instructions. It should be noted that some manufacturers recommend cleaning their electronics only by wiping the housing with a soft cloth dampened with a mild detergent and water to avoid disinfecting or cleaning solutions oxidizing the circuitry through corrosion.
4. For non-porous surfaces in patient-care compartments that are not frequently touched, detergent and water are sufficient for cleaning the surfaces. Cleaning methods that can potentially produce aerosols or mists should be avoided in the patient-care areas.
5. For small spills of bodily fluids, clean with detergent and water, and then disinfect using a hospital disinfectant in accordance with the manufacturer's instructions. Large spills of bodily fluids should be cleaned by removing any visible organic matter with absorbent material, then cleaned and disinfected using the same procedures.
6. Contaminated reusable patient care devices and equipment should be placed in biohazard bags labeled for cleaning. The devices and equipment should be disinfected or sterilized according to the manufacturer's instructions.
7. After cleaning, properly dispose used gloves then clean hands with soap and water or an alcohol-based hand gel. The ambulance staff should avoid touching the face with gloved or unwashed hands.

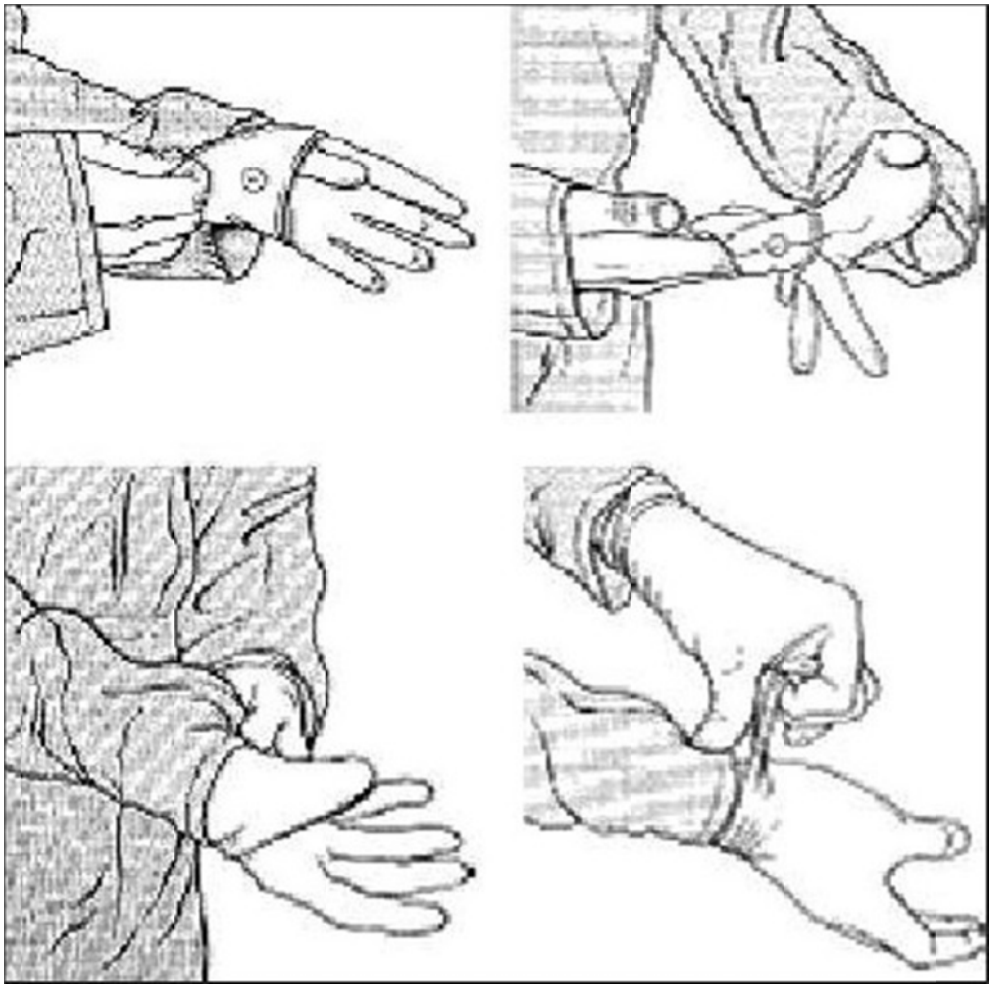


Figure 13 – Proper Glove Removal Technique

Regardless of the nature of contaminants or the situation, basic personal protective equipment such as disposable gloves must be worn during cleaning. Gloves should be worn before handling cleaning agents, and they cannot be reused and must be removed immediately after cleaning. To avoid cross contamination within the ambulance, gloves should be replaced frequently before touching disinfected surfaces or when leaving the vehicle. Figure 13 demonstrates the proper technique for removing used gloves. When taking off contaminated gloves, the user should fold the gloves inward, exposing the clean inside surface. The user

should take extra precaution avoid contacting bare skin with the outside surface of used gloves (Patwardhan, N., [33]).

CHAPTER 3. EMS CONTAMINANT ISOLATION ENGINEERING

3. Introduction

Medical ambulances are used all over the world during both rescue operations and transportation of the sick or injured. The primary purpose of an emergency medical ambulance is to provide pre-hospital care to patients with illnesses or injuries and transport them (Pollak, N. A., [3]). In areas of high ambulance usage quick turnover time is critical. The working environment inside of an ambulance must be clean and free of any contaminants such as bloodborne pathogens, airborne pathogens, and harmful gases.

Firstly, as mentioned before, turnover time for ambulances are critical especially for areas of high incident rates and/or limited number of ambulances. However, at the same time it is important to ensure that the ambulance is free of potential pathogens. Current ambulance decontamination methods can potentially use chemicals that pose a health threat to the workers and take time due to the manual labor. The revision of the decontamination procedures will entail the enhancement of current methods, chemicals, and if time permits, the proposal of a new interior design for ambulances.

Secondly, pathogens and hazardous material can be commonly found in our everyday lives. For example, a passenger on a bus coughing may merely have the common cold, or could potentially have the Influenza or even Tuberculosis. It is hard to definitively identify such threats and therefore universal precautions must be employed. However, to enforce such precautionary measures is also near to impossible. The revision of the current precautionary measures will merely entail comparing and modifying current devices that exist to make the ambulance a safer environment.

Thirdly, there are many biosensors and hazardous gas detectors that have been developed for various reasons. Some detectors are small and reliable enough that may be a viable candidate for use in the pre-hospital care environment. The identification of efficient, effective and reliable pathogen detection systems will entail research and proposal of currently available sensors and even sensors in the research and development phase.

Lastly, the project includes research and proposals of potential areas of enhancement for a more friendly emergency medical service. A summary of the project was presented to the team and our advisor, and can be found in Appendix J.

3.1 Worcester Emergency Medical Service Visit

Part of the background research that was needed for this project involved speaking with actual paramedics and discussing their first-hand experiences with working in the ambulances. One evening, our group had the opportunity to speak with a few paramedics from the University of Massachusetts Memorial Hospital and to observe the ambulances in which they work. Some of the questions that we had prepared before the meeting included, but were not limited to:

1. Do you clean KEDs, Splints, and traction devices after they are used? And if so how often?
2. What else do you clean?
3. Is there equipment that does not get cleaned after each run?
4. How often are stretcher mattresses cleaned?
5. What cleaning solutions do you use?
6. What protective equipment is required for the cleaning material being used?
7. How long does it take to clean?

8. Are there any instances where you have to be dispatched even when you are still cleaning?
9. What are some last minute actions you take when dispatched during cleaning?
10. Would you feel comfortable learning and using new cleaning procedures, given the new procedures are more effective?

Through our discussion with the paramedics, we were able to gain more of an insight into their environment. We learned about some of the major areas of concern for contamination, such as the creases between cushions: a difficult area that might collect blood due to the fact that the cushions are not removable. Also, the paramedics mentioned that various handles or railings for support could be a potential area for contamination, since they are constantly being touched by gloved hands which may have bodily substances on them. And because soiled gloves may not be replaced during patient care, radios and control panels may also be at risk for contamination. In fact, one of the main complaints the paramedics had were that the switches of the control panel had very small spaces in between them, making them nearly impossible to fully clean.

Many devices in the ambulance such as KEDs or short boards are constructed from materials that do not absorb contaminants such as blood, and therefore can be cleaned through scrubbing and disinfecting with germicidal wipes. Items that might absorb bodily fluids such as straps can be removed and washed, but if they become soiled to a great degree, they are disposed of and replaced.

For the actual cleaning process, we were told that it is usually up to the paramedic to clean the ambulance at the end of his/her shift, although some opt to clean the ambulance after each call. The thoroughness of the clean is also at the discretion of the paramedic. The individual we talked to regarding this subject mentioned that he typically likes to use a power washer using a

hose at the hospital to spray down areas of the ambulance. The cleaning process varies with the amount of contamination present in the ambulance, and can range between five and fifteen minutes in duration. The paramedic we spoke to mentioned that when cleaning the ambulance, he typically wears gloves, but no other form of PPE. However, should another call come in before the ambulance is fully cleaned, it is likely that only the major areas will end up being sanitized.

Some final things that we noted from our meeting with the paramedics were that they typically use bleach to clean the ambulance, which was among the cleansing agents that we had researched. In addition, one interesting thing we were told was that there was no drainage system in the ambulance and that any blood or bodily fluid that might spill onto the floor would just migrate around the floor of the ambulance as the ambulance moved, usually collecting at the bottom of some steps leading from the ambulance side door.

3.2 Ultraviolet Germicidal Irradiation

One of the first technologies we considered incorporating in the ambulance system was Ultraviolet Germicidal Irradiation (UVGI). This technology involves emitting light at a certain wavelength to kill pathogens exposed to it, in the air or on surfaces. Generally, it is hoped that such a device would be able to cut down on the amount of time needed to disinfect an ambulance between runs, and to cut down on the amount of labor needed to be done by the healthcare worker responsible for cleaning the ambulance. Also, it is desirable to have a device that is capable of disinfecting areas of the ambulance that might be difficult to reach through manual cleaning. In the healthcare industry, UVGI has mainly seen testing in hospitals, such as in patient rooms where hospitalized patients had been infected with pathogens such as MRSA. Without

properly decontaminating those hospital rooms after each use, there is “significant risk of acquiring [those] organisms from contaminated environmental surfaces” (Rutala, W. A., et al., [34]).

Figure 14 – Lumalier Corporation EDU UVGI Device

Pictured in Figure 14 is an example of a UVGI lamp. Manufacturers produce lamps to perform in many different settings, as a result, there are many different existing designs currently on the market. The UVGI lamp listed here is the EDU produced by the Lumalier Corporation; its function is “Portable germicidal disinfector for multiple [uses]” (Lumalier Corporation, [35]).

3.2.1 Background

As stated before, Ultraviolet Germicidal Irradiation involves emitting light at a certain wavelength to kill pathogens. Specifically, it uses a section of the electromagnetic spectrum where the wavelength is around 254 nm, also known as UV-C light. (Rutala, W. A., et al., [34]).

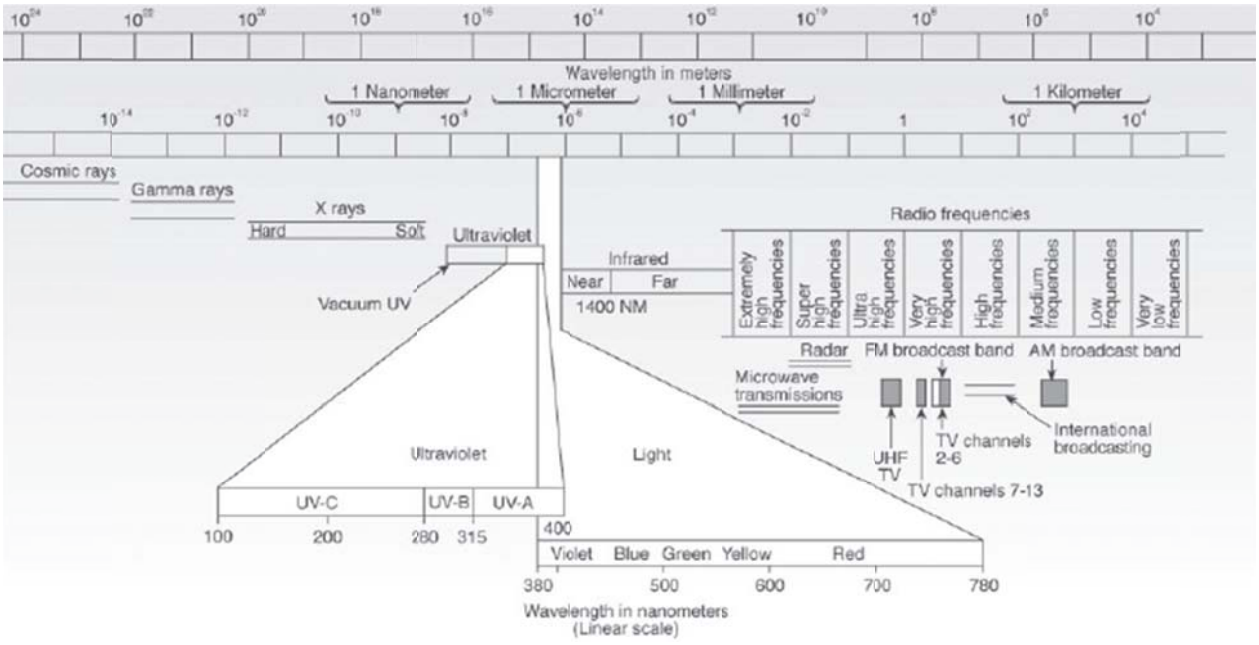


Figure 15 – Electromagnetic Spectrum

As can be seen in Figure 15, only a short section of the electromagnetic spectrum falls under what can be considered UV-C, approximately between 100 nm and 280 nm (Brickner, P. W., et al., [36]). However, below 254 nm, UV-C light can start producing ozone, which is harmful to humans, causing damage to lung tissue and the respiratory system (National Institute for Occupational Safety and Health, [37]). Typically, UVGI lamps are designed to only produce UV-C light around 254 nm, so ozone is not produced.

The effect of UV-C light on pathogens was first observed in the 1870s, and shortly after, it was soon demonstrated that it could be used to disinfect water. Eventually, processes were

developed where it was used to sterilize drinking water for the public (Kowalski, W. J., [38]). Today, it has many applications, including control of airborne diseases, and disinfection of air, surfaces, and instruments that need to be sterilized (Rutala, W., A., et al., [34]).

UV-C light works primarily through "inactivation of DNA and RNA through absorption of photons resulting in formation of pyrimidine dimers from thymine and cytosine" (Nerandzic, M. M., et al., [39]). Basically, UV-C light disrupts the genetic material of many microorganisms, which greatly inhibits the cell functions it needs to execute in order to stay alive. Because of this, UV-C can kill a wide variety of bacteria, fungi, viruses, and spores (Nerandzic, M. M., et al., [39]).

UV lamps are able to produce UV-C light at 254 nm because of their design. Generally, UV lamps work by having an electrical charge passing through mercury vapor at low pressure. The bulb is constructed of specific material, so that only light of a certain wavelength is allowed to pass through. As stated before, this is partially to prevent the production of ozone, which can have harmful effects. In addition, it is usually advised that the mercury content in the lamps be relatively low, such as 5 mg or less, due to the fact that bulbs or the lamp may need to be replaced and disposed of (National Institute for Occupational Safety and Health, [37]).

Figure 16 – UVGI Replacement Lamp

Figure 16 shows an example of a replacement bulb used in a UV lamp, as produced by Lumalier. Generally, they are relatively inexpensive, costing approximately $50 (Lumalier Corporation, [40]). Many studies conducted to test the effectiveness of UVGI have demonstrated that UV-C light substantially reduces contamination found on surfaces or in the air.

For the most part, many applications of UVGI involve either surface decontamination, upper room irradiation, or duct irradiance.

Surface decontamination involves using UV lamps in an area where it is well-positioned so that the UV-C light is in direct line of sight of as many contaminated surfaces as possible. Several studies have been conducted on a device called the TRU-D (Total Room Ultraviolet Disinfector), developed by the Lumalier corporation. The TRU-D is stated to be able to measure "UV-C intensities reflected from the walls, ceilings, floors, or other treated areas" so that it can be able to calculate the correct dose needed to eliminate pathogens (Owens, M. U., et al., [41]). One study conducted to evaluate the usefulness of such a UVGI device found that in a test room with vegetative bacteria and *C. difficile* spores prepared on formica sheets, a 99.9% reduction of the vegetative bacteria was achieved in 15 minutes, while a 99.8% reduction in spores was achieved in 50 minutes. This study also looked at the effectiveness of surface decontamination in actual patient rooms where patients had been placed under "contact precautions to prevent transmission of MRSE or VRE" (Rutala, W. A., et al., [34]).

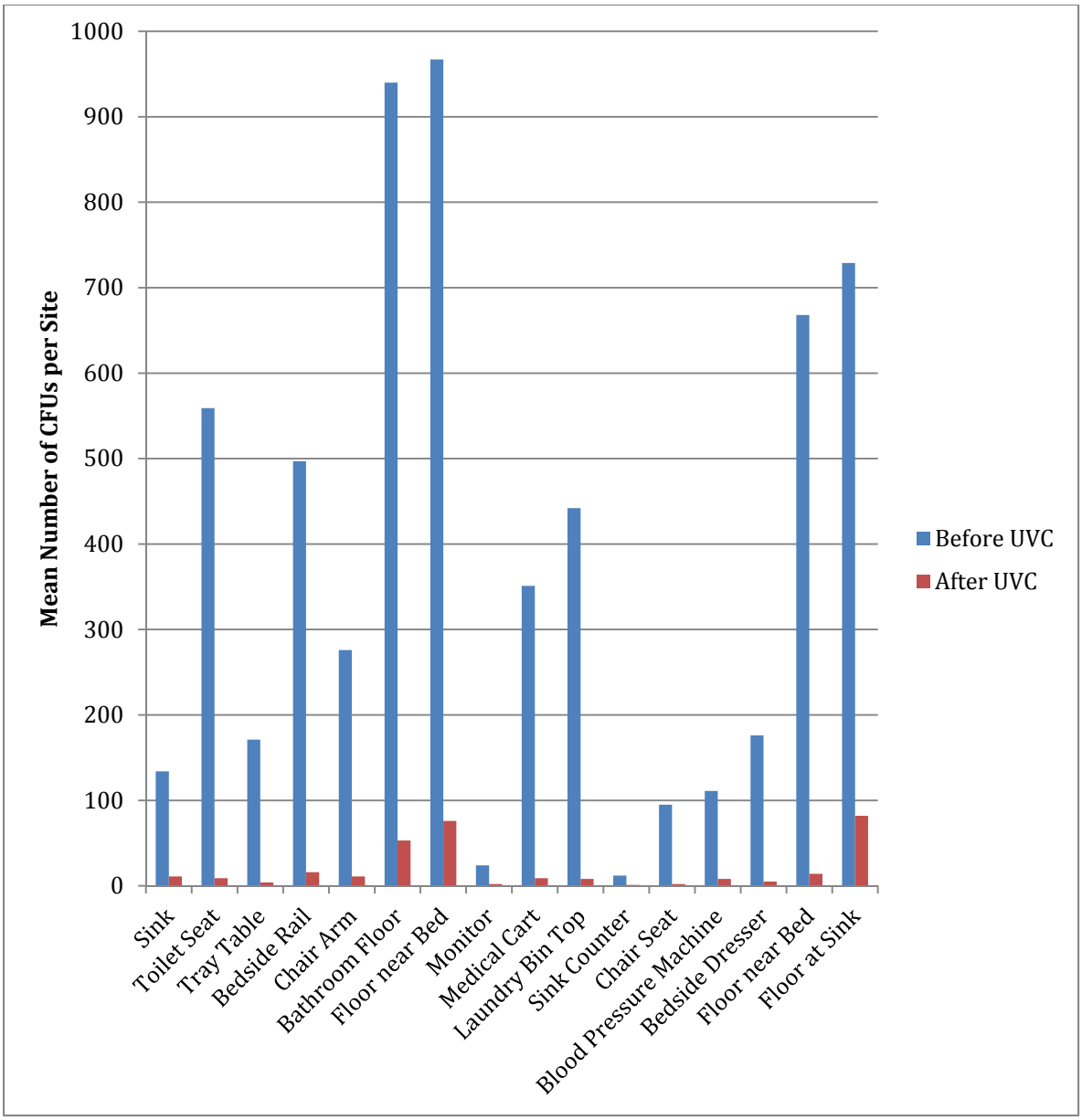


Figure 17 – Effects of UVC Light on CFUs

As Figure 17 shows, significant reduction of contamination was achieved after UV-C light had been applied. This data was obtained with a mean UV exposure time of only approximately 17 minutes. The study also mentioned that this particular surface decontamination device using UVGI was effective in reducing contaminants in both direct and indirect exposure of UV-C light (Rutala, W. A., et al., [34]).

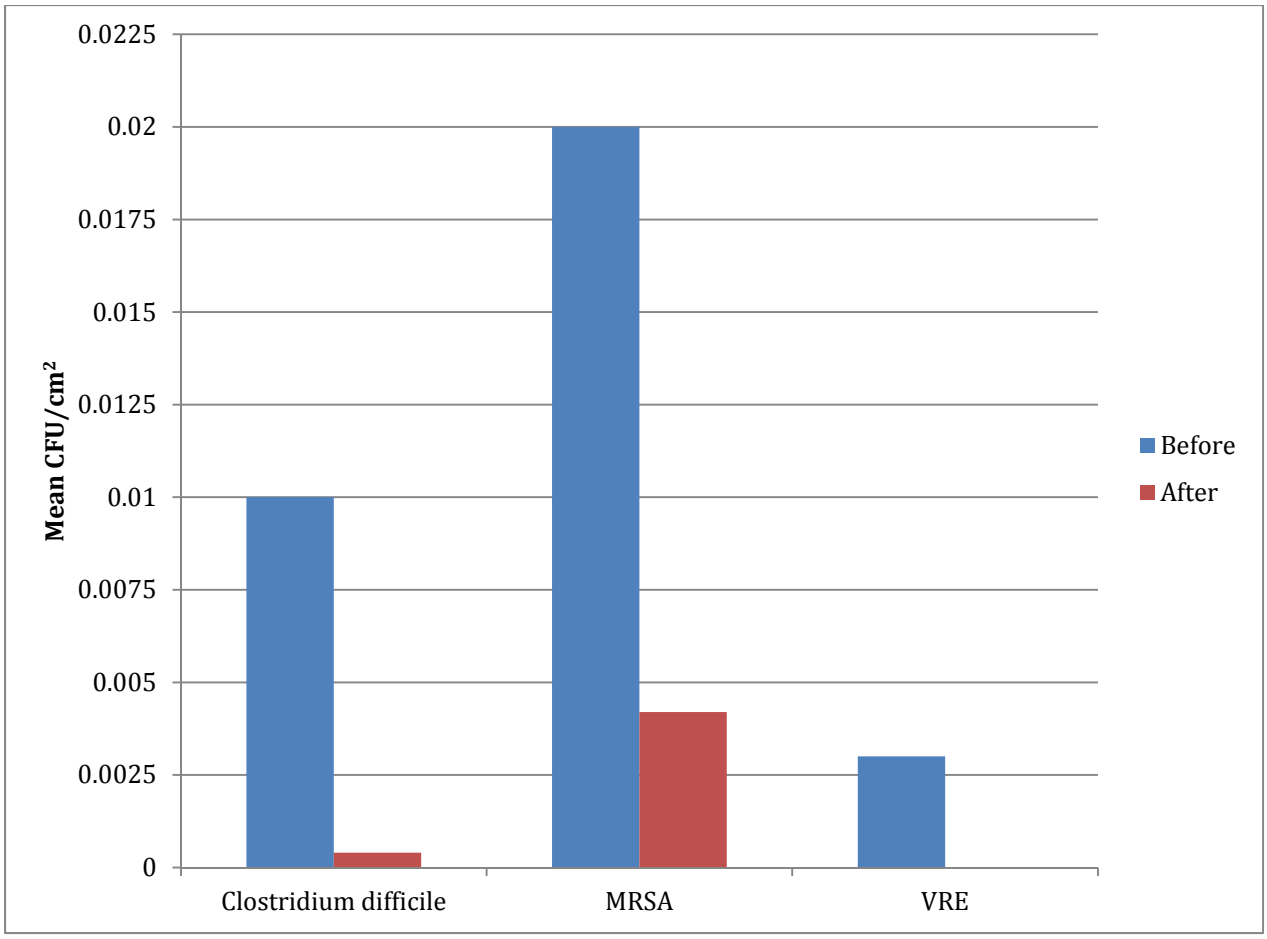


Figure 18 – Effects of UVC Light on CFUs of Pathogens of Concern

Another study performed a similar experiment using the TRU-D device in hospital rooms where patients had been on contact precautions for MRSA or *C. difficile*, and had not been cleaned by hospital staff yet. In the study, a total of 261 surfaces from 66 rooms were cultured to quantify the mean number of colony-forming units (CFU) per square centimater for each type of contaminant, both before and after application of UV-C light. As can be seen from Figure 18, UVGI caused a significant amount of reduction (Nerandzic, M. M., et al., [39]).

In the practice of upper room irradiation to remove contamination, UV lamp fixtures are suspended from the ceiling and/or installed onto the walls. They are set up so that all the

radiation is directed upwards, so that the occupants below are not exposed. This creates an "intense zone of UVGI" in the upper levels of the room, effectively killing airborne pathogens that enter. This sytem requires, however, some air mixing to ensure that microorganisms in the lower levels of the room eventually reach the UVGI zone (Center for Disease Control and Prevention, [42]).

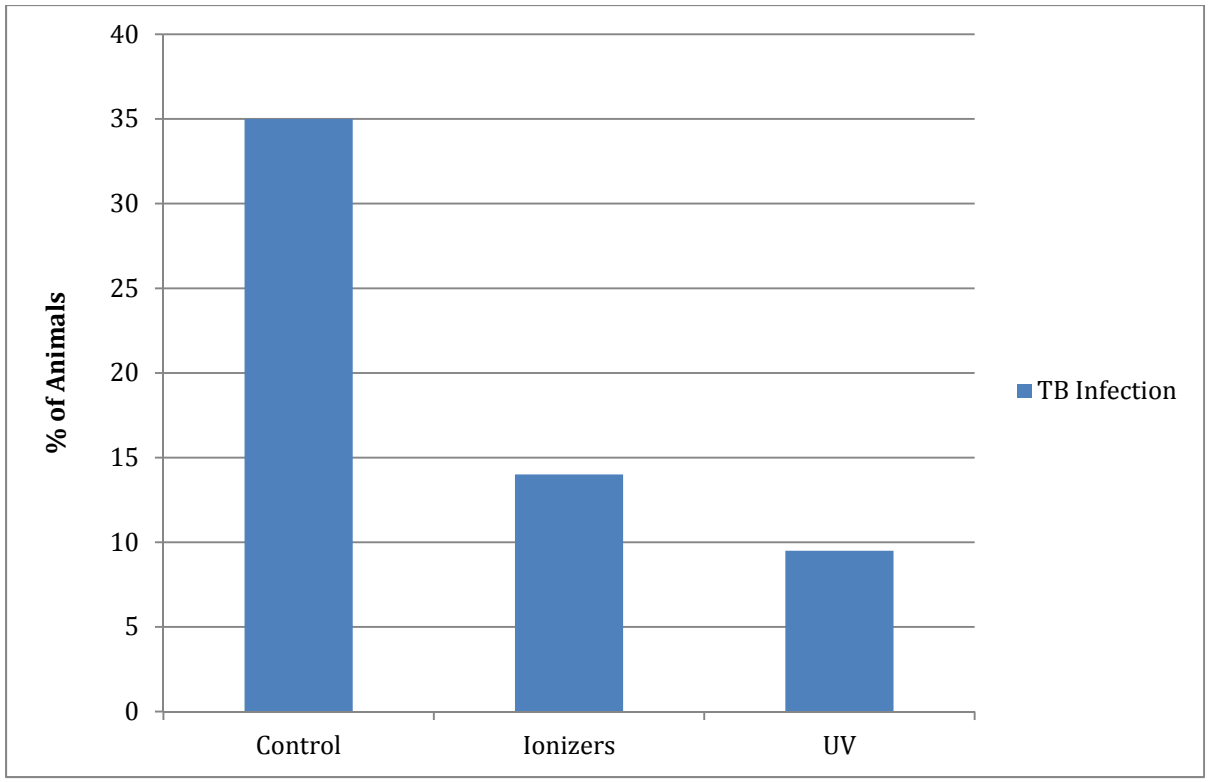


Figure 19 – Effects of Upper Room UVGI and Air Ionizers in Preventing TB Infection

In a study conducted in Lima, Peru inside a HIV-TB ward in a hospital, three groups of guinea pigs were exposed to ward air in order to test the effectiveness of UV lights and negative air ionization. As can be seen from the recreated table results in Figure 19, UV lights demonstrated the highest likelihood prevention for developing tuberculosis infection or disease. As the study's analysis using an airborne infection model stated, "ionizers prevented 60% of TB infection and 51% of TB disease, and that UV lights prevented 70% of TB infection and 54% of

TB disease." Based on this analysis, they concluded that "UV lights tended to be more protective than ionizers" (Escombe, A. R., [43]). A number of other studies come to a similar conclusion that upper room irradiation provides "useful air disinfection" (Brickner, P. W., [36]).

Due to the fact that ambulances do not have large air ducts, the concept of duct irradiation as a means of providing UVGI has not been explored in-depth for this project. It is still worthwhile, however, to give it a brief mention. For this form of UVGI, UV lamps are placed inside air ducts to disinfect exhaust air before it circulates back into the room. In duct irradiation, it is important that the flow rate of air through the ducts is not too high, due to the fact that each pathogen has a specific residence time of UV-C exposure needed to become deactivated. Generally, UV lamps in air ducts are seen as a supplementary measure to HEPA filters, and not as a replacement (Center for Disease Control and Prevention, [42]).

3.2.2 Product Details

In order to perform some analysis on the existing pieces of UVGI technology currently on the market, several pieces of equipment of varying designs and purposes were selected and analyzed. This analysis included investigating properties such as time needed to reduce 99% of select pathogens, initial costs, operation costs, and size (refer to appendix D for exact product specifications and images). The products researched mainly came from two companies: Lumalier Corporation, and American Air and Water, Inc. All of these products were studied to see how each would fare if implemented into the ambulance setting. Although some products did not list all of the information we desired for complete analysis, through similarities of products between the two aforementioned companies, we were able to at least gain a vague idea of the properties possessed by each device type. From American Air and Water, Inc, the devices we looked into

included: the AAW Handheld Ultraviolet Germicidal System (a handheld device), the AAW-TBE-14-1 In-Room Ultraviolet Germicidal System (an air purifier), and the MRS3684P Mobile Room Sterilizer (a mobile room sterilizer). From Lumalier Corporation, the devices we looked into included: the BLU236 and BLU436 (a series of ceiling mounted disinfectors), the ADU (a ceiling mounted disinfector specifically designed for ambulances), and TRU-D (a mobile room sterilizer). Product specifications from the websites of Lumalier and American Air and Water can be seen in Appendix D.

Part of the analysis needed to evaluate each product was to understand the intensity of the UV-C light that each device produced. Some products, such as the ones from American Air and Water listed the intensity of the light sources. Some products from Lumalier Corporation, however, only listed UV-C watts. Still, we were able to notice from a table provided by American Air and Water for replacement UV lamps that the UV Intensity at one meter was approximately equal to the UV output multiplied by 10.8.

Table 9 – UV Lamps Table from American Air and Water, Inc

Length	Lamp Model	Lamp Description	UV Output (W)	Lamp Intensity (μW/cm² @1 m)
6''	GML170	Hot Cathode Lamp	0.5	5.4
12''	GML125	Slimline Lamp	6.0	66
16''	GML430	High Output Lamp	10.0	108
24''	GML435	High Output Lamp	16.2	175

The abridged table, Table 9, details the UV output and UV intensity for each lamp model sold by American Air and Water. The table in its entirety can be seen in Appendix B. Although it is not exact, it can be seen how the UV output in W (watts) multiplied by 10.8 is approximately

equal to the UV intensity in μW/cm² at one meter from the surface (American Air & Water, Inc., [44]).

Table 10 – UV Dosage Table

Organisms:	Energy Dosage of Ultraviolet radiation (UV dose) in μWs/cm^2 needed for kill factor	
Bacteria	90% (1 log reduction)	99% (2 log reduction)
Bacillus anthracis - Anthrax	4,520	8,700
Bacillus anthracis spores - Anthrax spores	24,320	46,200
Clostridium tetani	13,000	22,000
Corynebacterium diphtheriae	3,370	6,510
Ebertelia typhosa	2,140	4,100
Escherichia coli	3,000	6,600
Mycobacterium tuberculosis	6,200	10,000
Salmonella typhosa - Typhoid fever	2,150	4,100
Shigella dyseteriae - Dysentery	2,200	4,200
Staphylococcus aureus	2,600	6,600
Vibrio comma - Cholera	3,375	6,500
Molds	90%	99%
Aspergillius flavus	132,000	330,000
Virus	90%	99%
Infectious Hepatitis	5,800	8,000
Influenza	3,400	6,600
Poliovirus - Poliomyelitis	3,150	6,600

Also from American Air and Water, Table 10 was made for many microorganisms, detailing the energy dosage of ultraviolet radiation need to achieve a 90% or 99% reduction. For each of the products, the UV intensity was listed, in some cases needing to be calculated first from UV output (American Air & Water, Inc., [45]).

Table 11 – Product Specification Table

Product Name	Nominal Watts (W)	UV-C Watts (W)	UV Intensity ($\mu W/cm^2$ @1 m)
AAW Handheld Ultraviolet Germicidal System	*4.7*	*1.6*	*17.1*
AAW-TBE-14-1 In-Room Ultraviolet Germicidal System	*14.2*	*4.7*	*51.1*
MRS3684P Mobile Room Sterilizer	*264*	*88*	880
BLU236	72	24	*240*
BLU436	144	48	*480*
ADU	36	12	*120*
TRU-D (Total Room Ultraviolet Disinfector)	Unavailable	Unavailable	Unavailable

Table 11 lists the UVGI products listed before. The cells in italics indicate a calculated estimate. The product specifications found for the Lumalier devices only listed the nominal watts, and the UV-C watts. Thus, the UV intensity for the Lumalier products was approximated by multiplying the UV-C watts by 10.8, due to the observation that the ratio of UV intensity from 1 meter to UV-C watts was equal to 10.8. The product specifications for the American Air and Water, Inc. only listed the UV intensity, so UV-C watts was approximated by dividing by 10.8. As for the nominal watts, it was observed that UV-C watts was equal to one third of the listed nominal watts in Lumalier products. Therefore, the calculated UV-C watts was multiplied

by three to find the approximate value for nominal watts. However, the UV intensities provided by the product details were expressed at a distance of six inches for the handheld device and one foot for the air purifier. In the interests of keeping the UV-intensities consistent for all products, they were converted to find the UV intensity at a distance of one meter, similar to the provided table for the UV lamps. In order to convert the UV intensities, the Inverse-Square Law was used.

$$\frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2$$

When this equation was used, I_1 was the UV intensity provided by American Air and Water, and d_1 was the distance (converted to meters) for the provided UV intensity. I_2 was the UV intensity that we tried to solve for, and d_2 was equal to one meter.

For the TRU-D, and the similar product from American Air and Water, the MRS3684P, neither wattage nor UV intensity was listed in the product specifications. For the MRS3684, however, it was mentioned that the product utilized eight GML100 lamps, which each possess a UV intensity of 110 μW/cm² at one meter. In order to approximate the total UV intensity of the device, we chose to multiply 110 μW/cm² by eight. This is an approximation – it is very likely that since each lamp is not the same distance away from a particular surface, it is an overestimate. Although the MRS3684 and the TRU-D have similar functions, and even look vaguely alike, we felt that we could not estimate the properties of the TRU-D from the properties of the MRS3684 due to the fact that the TRU-D used a different number of lamps of unknown UV intensity.

With the UV intensities calculated for most of the products researched from Lumalier and American Air and Water, it was then possible to calculate the time needed to achieve a 90% of 99% reduction of various pathogens. The time needed to achieve a desired reduction of a particular microorganism was calculated by the following equation.

$$Time\ (seconds) = \frac{UV\ Energy\ Dosage\ (\mu\frac{W \times s}{cm^2})}{UV\ Intensity\ (\mu\frac{W}{cm^2})}$$

The UV Energy Dosage mentioned in the equation refers to the dosages listed in Table 10. The UV Intensities refer to the ones calculated earlier in Table 11. It must be remembered that since each UV Intensity was calculated at a distance of one meter, the following calculated times assume a distance of one meter between the UV-C light source and the surface.

Table 12 – UVGI Device Reduction Times for Major Contaminants

Organisms	UV Dose Needed	Time Required for Reduction (seconds)					
Bacteria	99% (2 log reduction)	AAW Handheld	AAW-TBE-14-1 In-Room	MRS3684P	BLU236	BLU436	ADU
Bacillus anthracis - Anthrax	8,700	508.77	170.25	9.89	33.56	16.78	67.13
Bacillus anthracis spores - Anthrax spores	46,200	2701.75	904.11	52.50	178.24	89.12	356.48
Clostridium tetani	22,000	1286.55	430.53	25.00	84.44	42.44	169.75
Corynebacterium diphtheriae	6,510	380.70	127.40	7.40	25.12	12.56	50.23
Ebertelia typhosa	4,100	239.77	80.23	4.66	15.82	7.91	31.64
Escherichia coli	6,600	385.96	129.16	7.50	25.46	12.73	50.93
Mycobacterium tuberculosis	10,000	584.80	195.69	11.36	38.58	19.29	77.16
Salmonella typhosa - Typhoid fever	4,100	239.77	80.23	4.66	15.82	7.91	31.64
Shigella dyseteriae - Dysentery	4,200	245.61	82.19	4.77	16.20	8.10	32.41
Staphylococcus aureus	6,600	385.96	129.16	7.50	25.46	12.73	50.93
Vibrio comma - Cholera	6,500	380.12	127.20	7.39	25.08	12.54	50.15
Molds	99%						
Aspergillius flavus	330,000	19298.25	6457.95	375.00	1273.16	636.58	2546.33
Virus	99%						
Infectious Hepatitis	8,000	467.84	156.56	9.09	30.86	15.43	61.73
Influenza	6,600	385.96	129.16	7.50	25.46	12.73	50.93
Poliovirus - Poliomyelitis	6,600	385.96	129.16	7.50	25.46	12.73	50.93

Table 12 details the amount of time needed to reduce various contaminants. Although the UV Energy Dosage for many microorganisms were provided (as can be seen in Appendix C), the reduction time was only calculated for the select contaminants above. For the devices that have a relatively high UV intensity (>100 μW/cm² @1 m), most bacterial species and viruses can be reduced by 99% in close to a minute or under. Molds and bacterial spores, however, take quite a bit longer. Even devices that have a lower UV intensity (<100 μW/cm² @1 m) can eliminate most of the contaminants in the above table in only a few minutes.

Another property of interest for each of the UGVI products discussed thus far is cost. Certain products may cost more than others, or may consume more power, which means higher operation costs. One equation that we found described the operating cost of a device that runs off of power from an outlet (Kowalski, W. J., [38]).

$$Operating\ Cost\ (\$) = \frac{P \times H}{1000} \times P_c$$

For this equation, P was equal to the total watts of power consumed by a lamp fixture. H was equal to the total number of hours in a year for which the device would be in use. P_c represented the power charge, which we approximated as being 0.1 $/kWh. In order to calculate the operating cost, we used the nominal watts listed in Table 11 as the total watts of power consumed, P. For H, we assumed a value of 750 hours, or a little over 2 hours of use a day.

Table 13 – Operating and Initial Costs

Product Name	Nominal Watts (W)	Operating Cost ($)	Selling Price ($)
AAW Handheld Ultraviolet Germicidal System	4.7	0.35	400.00
AAW-TBE-14-1 In-Room Ultraviolet Germicidal System	14.2	1.07	499.00
MRS3684P Mobile Room Sterilizer	244.4	18.33	7399.00
BLU236	72	5.40	Unavailable
BLU436	144	10.80	Unavailable
ADU	36	2.70	Unavailable
TRU-D (Total Room Ultraviolet Disinfector)	Unavailable	Unavailable	Unavailable

In Table 13, the equation for operating cost was evaluated for each device, based off of its nominal watts value. In addition, the table displays the selling price for some of the devices, as stated by the company. Although we were able to find prices for products from American Air and Water, at the time of writing for this project, we have been unable to ascertain selling prices for products from Lumalier. As the table shows, the yearly operating cost of using devices,

assuming they can be plugged into an outlet, is quite low. It would seem that a large part of the cost that comes from using a UVGI device would be the initial cost from purchasing one.

Another property of interest to investigate the viability of using these UVGI devices in the ambulance was size. In the ambulance setting, there is a limited amount of space. A large amount of the volume of the ambulance's interior is used for both equipment and space for the patient and paramedic. An investigation into the space needed for each device is necessary to determine whether it should be a permanent, removable, or whether it should even be used at all.

Table 14 – Physical Dimensions

Product Name	Length (in)	Width (in)	Height (in)	Volume (in^3)
AAW Handheld Ultraviolet Germicidal System	18	5	6.25	562.5
AAW-TBE-14-1 In-Room Ultraviolet Germicidal System	20	5	4	400
MRS3684P Mobile Room Sterilizer	20	20	48	19200
BLU236	18	8	4.5	648
BLU436	36	8	4.5	1296
ADU	18	5	3	270
TRU-D (Total Room Ultraviolet Disinfector)	Unavailable	Unavailable	Unavailable	Unavailable

Using the available specifications for each of the UVGI devices from American Air and Water and Lumalier, the general physical dimensions and weights for the products were tabulated in Table 14. Not every specification was given for all products, however, and to try and estimate missing information by using general material compositions or comparisons to slightly similar products would still only result in little more than guesses. But from a general look at the data, it would seem the only item that could not be a permanent fixture within the ambulance is the MRS3684P Mobile Room Sterilizer, due to the fact that it is quite large. It may be possible to move it into the ambulance as needed, during periods of when the ambulance is not in use. The weight of the device is not known, however, and so it might be extremely difficult to lift and place in the ambulance. The BLU236, BLU246, and the ADU might be implementable as permanent fixtures within the ambulance since they are ceiling fixtures with a relatively low height, so as not to adversely affect head clearance. Although not much is known about ideal placement for the AAW-TBE-14-1 In-Room Ultraviolet Germicidal System, the fact that it probably does not need to be placed in the center of the ceiling like some of the other devices, and that it has a reasonable volume might indicate that it is also a candidate for being a permanent fixture. The AAW Handheld Ultraviolet Germicidal System is described as being a handheld device, so installing it as a permanent fixture within the ambulance might not be necessary. Its size does not preclude its use in the ambulance, however.

3.2.3 Analysis

After doing research into the mechanism behind UVGI, the scientific literature evaluating its effectiveness, and the details of products currently in existence, we were able to arrive at a few conclusions regarding the viability of implementing such a technology in the ambulance setting.

There are several positive aspects to using UVGI devices in the ambulance. As can be seen in an analysis of the scientific literature, it can be very effective at reducing a large percentage of microorganisms in a reasonable amount of time in the hospital setting. One of the major appeals to using such devices is that many of them are automated; meaning that little manual labor might be expected of paramedics responsible for decontaminating the ambulance. Also, many of the devices currently in existence are of a reasonable size and portable, meaning that there exists a possibility to implement such devices in the ambulance permanently. Even if space does not permit the usage of such devices in a permanent capacity, much of the ambulance cleaning takes place in a setting with appropriate cleaning tools, and so it might be assumed that UVGI devices could be kept at these locations to be added and removed as needed for the cleaning process. In addition, our analysis of some of the products on the market indicate that the cost of operating such devices using an outlet is relatively inexpensive, especially considering how the intermittent need for ambulance cleaning precludes the need for continuous running of the devices. In addition, bulbs are advertised at being capable of working up to 8000-12000 hours of continuous use (American Air & Water, Inc., [44]), and so it is very possible that ambulance crews could go a long time without the need to replace lamps.

There were some drawbacks that we discovered during our analysis, however. Although the operating cost of using UVGI devices were relatively inexpensive, the initial purchasing

costs of the devices might be too much for an emergency medical department's budget. In addition, although it has been previously mentioned that UV-C light is effective at reducing contamination, it has been mentioned by some that the existence of dust or dirt can significantly inhibit the ability of radiation to eliminate microorganisms (Rutala, W. A., et al., [34]). Therefore, manual labor for cleaning the ambulance would still be needed, in order to remove all the dust and dirt. Finally, as mentioned before, UV-C light can be a safety concern. Human exposure to the radiation can result in sunburns, and painful inflammation of the cornea in the eye (Nardell, W. A., [46]). Remotely controlled devices should be used with caution, and care should be taken to ensure that automatic devices such as the TRU-D have properly working failsafes that terminate emission of UV-C light when movement is detected, such as the opening of a door (Nerandzic, M. M., et al., [39]).

Some of the sources of error in this analysis might arise from the fact that the vast majority of the literature written on UVGI has taken place in the hospital setting. There might be unforeseen drawbacks to using a UVGI device in an ambulance versus a hospital room, and studies should be conducted to ensure efficacy. But due to the fact that UV dosage increases when surfaces are closer to the light source, and that ambulance patient care area is significantly smaller than a hospital room, it is very possible that the reduction time is lower in an ambulance than in a hospital. Some other sources of error that might arise from our analysis would be for our operating cost. We made a rough estimate of the operating cost by using an equation that assumed the devices were running of power from an outlet. It is very possible that some of the currently existing devices run on batteries, and thus the operating cost might be greater. Finally, our results are based off of an analysis of UVGI devices from only two companies, many of which provided products that served different functions from one another. For a more accurate,

general picture of any type of UVGI device, more products of a similar function from different manufacturers would need to be compared simultaneously.

3.3 High Efficiency Particulate Air

Responsible for millions of infections and death every year, airborne diseases are spread through the air when droplets of pathogens are expelled due to coughing, sneezing, or talking. In addition, some of the pathogens are capable of surviving for weeks after the air droplets have settled on surfaces. Common examples include influenza, tuberculosis, chicken pox, and meningitis, airborne disease pose serious threats to emergency responders in ambulance settings.

A number of preventative measures can be used to effectively reduce the chance of infection from airborne diseases. As mentioned in the previous chapter, personal protective equipment such as masks can protect the ambulance staff by filtering out most of the pathogenic airborne particles. However, it can be challenging to implement frequent use of intrusive PPEs such as facial masks among emergency responders. Also, PPEs do not disinfect or neutralize the pathogenic droplets in the air. When paired with medical-grade High Efficiency Particulate Air (HEPA) filters, air filtration can effectively reduce the concentration of pathogenic droplets in the air by filtering out the particles during air circulation and ventilation. HEPA filters differ from standard residential filters in their added ability to trap contaminants that are as small as 0.3 microns in diameter (United Sates Department of Energy, et al., [47]).

Figure 20 – HEPA Filter Capability

Figure 20 demonstrates the various particulate sizes that the HEPA filters can trap. Capable of filtering out 99.995% of all airborne contaminates, air filtration systems incorporated with medical-grade HEPA filters can neutralize 100% of the airborne microorganisms with UVGI installed adjacent to the filter (United Sates Department of Energy, et al., [47]).

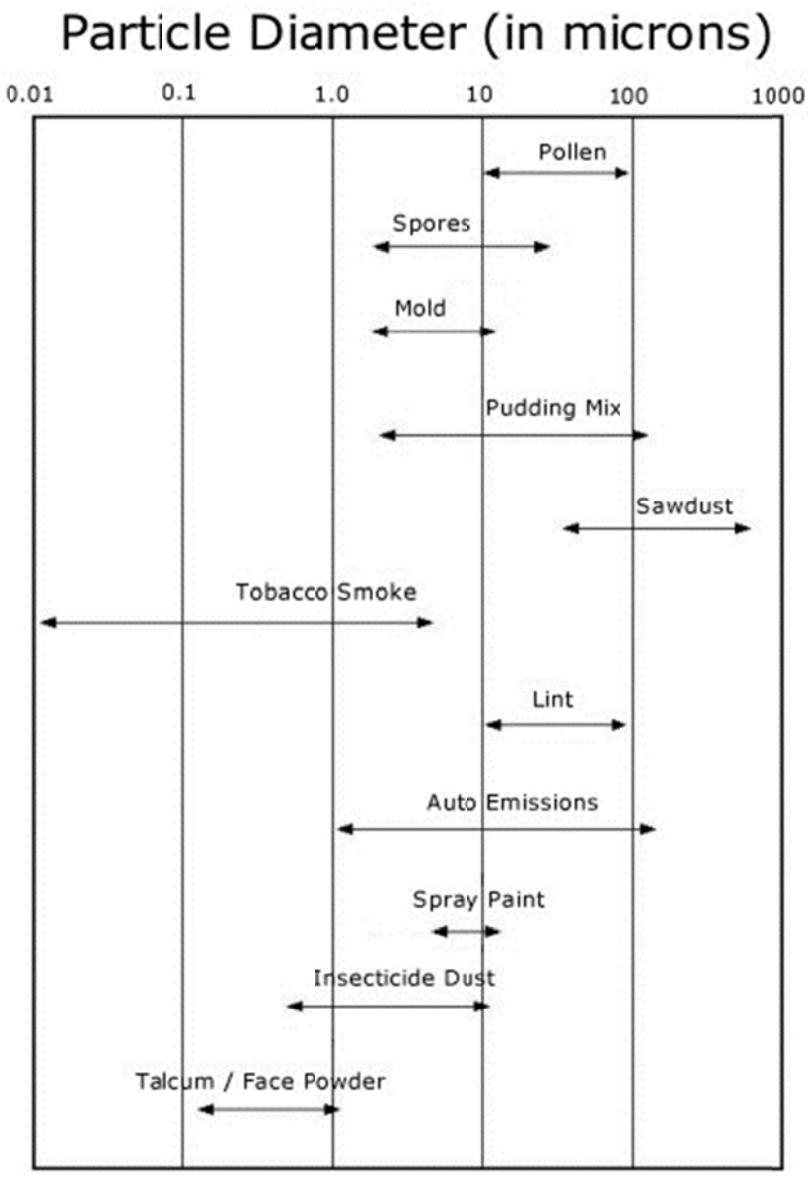


Figure 21 – Relative Particulate Size

Figure 21 shows approximate particulate sizes of many different items, some of which are relevant to the ambulance setting. Measuring approximately 1-5 microns in diameter, typical mold and bacteria spores are well beyond the minimal filtration capability of 0.3 microns and can be easily trapped in the filter. Under compact ambulance settings with minimal ventilation, transmission of any airborne diseases can be effectively terminated with the implementation of HEPA equipped air filtration systems.

3.4 Biosensors

The detection and identification of pathogenic bacteria and viruses are vital to the prevention of disease transmission in ambulance settings, in addition to proper treatment of infected EMT's. Although conventional methods are capable of accurately detecting biological substances, they usually involve time consuming procedures that take up to several days to yield results. Therefore, a new method of pathogen detection is urgently needed, and the rising biosensor technology brings promise of near real time detection of pathogenic substances that is as sensitive and reliable as conventional methods. A pathogen biosensor is defined as an analytical device that converts a biological response to an electric or visual signal, which is used to detect and identify the presence and concentration of biological substances such as pathogenic bacteria and viruses. Biosensors often utilize biological systems like enzymes, antigens, cDNA, and B cells as means of detection (Heo, J., et al., [48]). Common examples are blood glucose meters and pregnancy tests, which incorporate corresponding antigens for detection of interested substances in blood and urine.

3.4.1 Background

In order to function accurately and effectively, all biosensors must satisfy several requirements. First, they should be highly accurate, sensitive, and show a low detection limit. Since most bacteria have very high proliferation rate, a small number of undetected pathogenic bacteria and viruses can pose a serious risk to patients. In addition, a number of government agencies such as USDA require zero tolerance of certain strains of bacteria including E. coli and Salmonella. Second, the biosensors should have a rapid analysis time, which allows for immediate countermeasures to be taken. Third, the detection processes used by the biosensors should not be affected by unsteady surrounding environment such as pH or temperature. The reduced need for a controlled environment minimizes the use of lab equipment for preparation and allows for on-site real time monitoring. Fourth, the biosensors should be able to detect and identify different strains of bacteria simultaneously within a sample. One method to achieve this goal is to use multiple arrays of different sensors showing specificity toward different cells. Lastly, all biosensors should be cheap, portable, and easy to use, which allows operation by semi-skilled users without prior knowledge of lab techniques and skills (Olivier, L., et al., [49]).

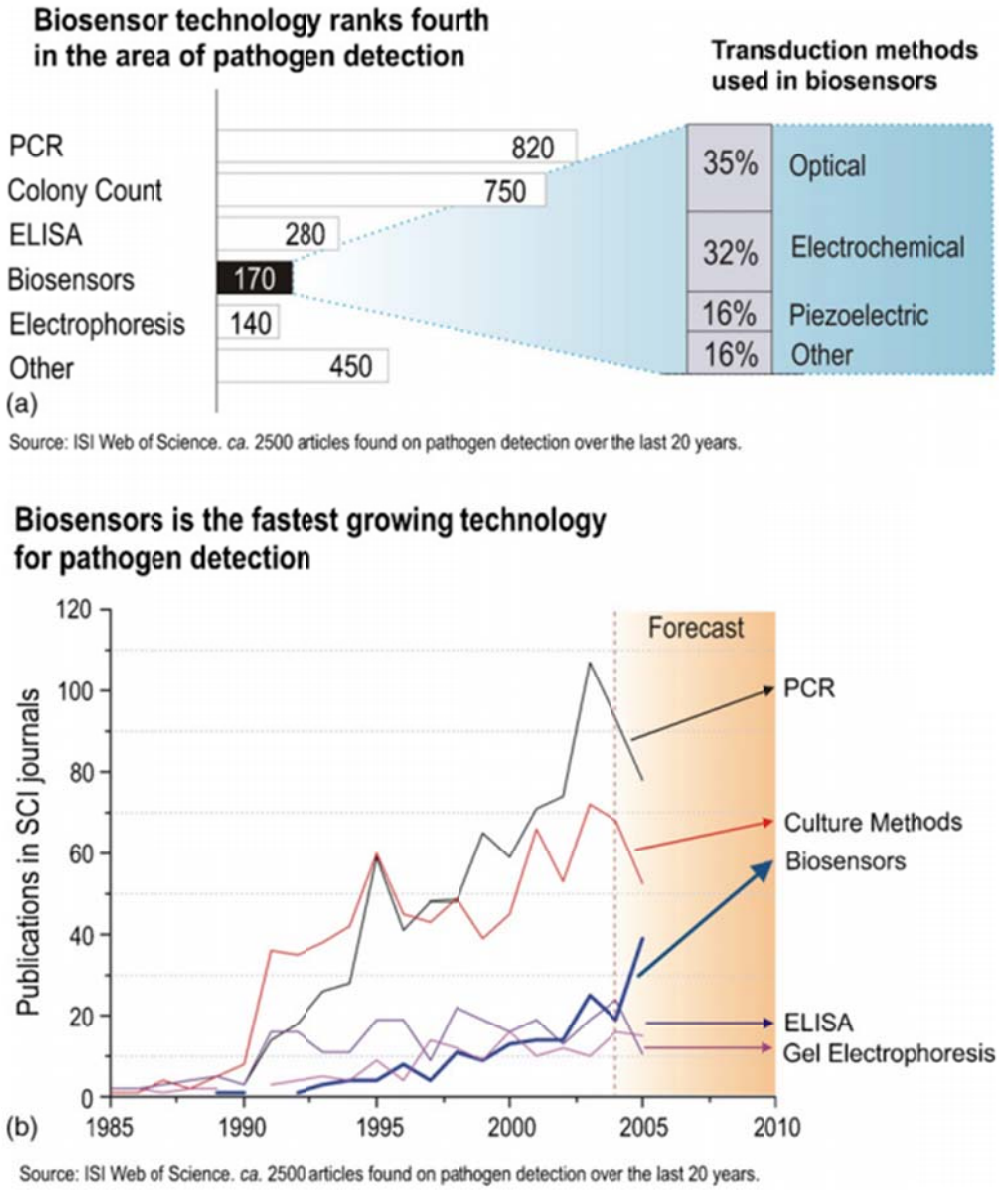


Figure 22 – Relative Rates of Technology Growth

Studies have been conducted on the number of works published on detection of pathogens over the last years (Olivier, L., et al., [49]). The result showed a rapid increase in the growth rate of biosensor technology for pathogen detection, as shown in Figure 22. Mainly composed of optical, electrochemical, and piezoelectric sensors, the use of biosensors in pathogen detection was predicted to soon surpass the widely popular ELISA-based detection method. In recent years, a number of advanced automated biosensors have become

commercially available on the market, with numerous promising biosensors almost completing development.

3.4.2 Product Details

One of the focuses of our project is to evaluate current biosensors and determine the viability and feasibility of implementing them in ambulance settings. A number of biosensors that are currently available on the market or are at the end of their development were evaluated based on their ability to detect pathogens from different types of transmission routes. "Bio-lab on a microchip" invented by a Caltech graduate, Frederick Balagadde, promises rapid, simultaneous detection of bloodborne pathogens from up to 100 samples at a time. Unlike traditional methods of bloodborne pathogen detection such as ELISAs, which lack the ability to detect multiple pathogens from different samples simultaneously, Bio-lab on a microchip is capable of performing multi-pathogen detection from a large sample pool in only 4 hours (Balagadde, F. K., [51]).

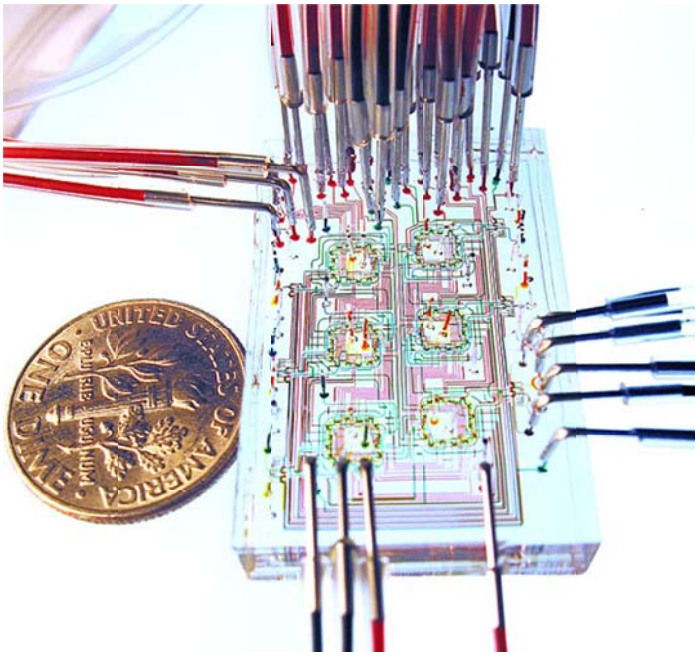


Figure 23 – Bio-lab on a Microchip

Figure 23 demonstrates the intricacy and small size of the biosensor. Based on similar principles of miniaturization that have benefited the computer and electronics industry, Bio-lab on a microchip miniaturizes biological and chemistry laboratories onto microfluidic chips that can fit in the palm of the hand. Composed of channels that are about the size of a human hair, the bio-chip has integrated valves, pumps, mixers, and injectors (Balagadde, F. K., [51]). As a result, an entire diagnostic experiment could be done with the miniaturized microfluidic system.

The PANTHER sensor created by MIT Lincoln Lab was also evaluated due to its unique ability to detect airborne pathogens in less than three minutes. Abbreviated from "Pathogen Notification for Threatening Environmental Releases", PANTHER is the only sensor currently on the market that utilizes immune cells for rapid pathogen detection and identification (Petrovick, M. S., et al. [50]). Most other available sensors generally rely on immunoassays or polymerase chain reaction (PCR), which take much longer to complete and are not as sensitive as PANTHER (Olivier, L., et al [49]).

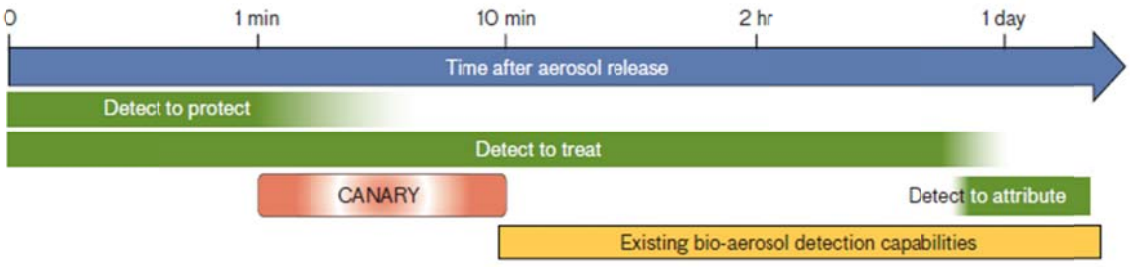


Figure 24 - CANARY Technology for Fast Detection

CANARY, Cellular Analysis and Notification of Antigen Risks and Yields, detects pathogens in the air by screening for soluble protein toxins and DNA and RNA sequences. Incorporated with PANTHER, the flexible biological aerosol identification sensor is useful for building protection, emergency response, rapid screening, and environmental monitoring. The CANARY technology is the only existing bio-aerosol detection system currently available on the market that is quick enough to enter the short time window that allows for both treatment and protection in the presence of airborne pathogens as demonstrated in Figure 24. The CANARY technology is primarily based on genetically engineered B cells, a type of white blood cells that binds directly to pathogens (Petrovick, M. S., et al. [50]). As the fastest pathogen identifier known, the white blood cells are modified by the researchers to bind specifically to pathogens of interest and emit photons to report the occurrence upon binding. The light emission is then picked up by the CANARY sensor and analyzed on a computer.

3.4.3 Analysis

Although most biosensors are automated and require little to no user intervention, there are still major financial and technical obstacles to overcome before biosensors can become a real alternative to traditional methods of pathogen detection. Unfortunately, biosensors currently available on the market are simply too expensive and are too limited in detection capabilities to

be implemented into ambulances. Although both the bio-lab on a microchip and PANTHER promise rapid detection of bloodborne and airborne diseases, both systems require intricate preparations that would restrict and obstruct an emergency responder's regular duties. In addition, the implementation of sensors like the PANTHER system would require resign of the ambulance interior due to their large sizes. For instance, the most compact version of PANTHER still measures one cubic foot, as seen in Figure 25.

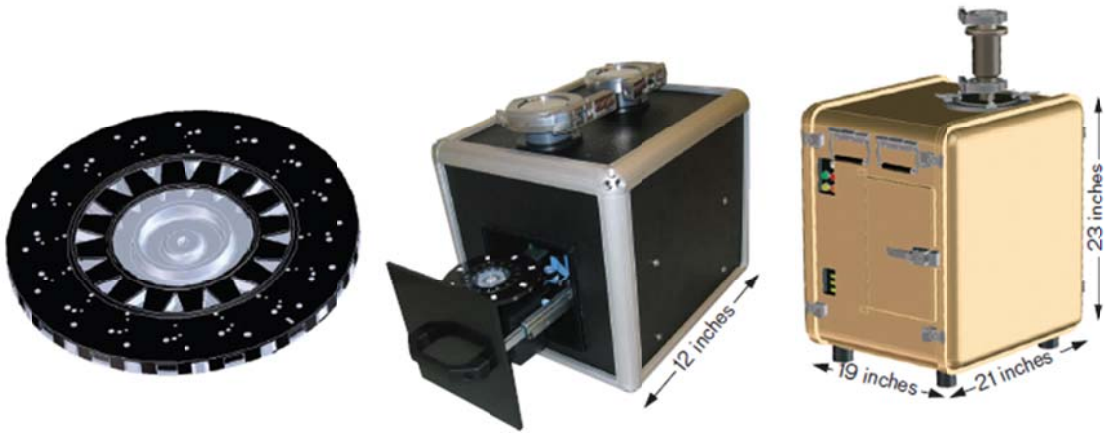


Figure 25 – PANTHER Dimensions and Components

The biosensors studied in this project were deemed unsuitable for in ambulance settings primarily due to their heavy dependence on laboratory preparation. For ambulance usage, future biosensors should be capable of detecting bloodborne and airborne pathogens in a small package, while requiring little to no human intervention. Driven by a large potential market, the biosensor is the fastest growing technology for pathogen detection, and will soon move ahead of the widely used ELISA based detection methods (Olivier, L., et al [49]). As the technology continues to advance, new forms of cheaper, more efficient and effective biosensors will inevitably start to emerge in the near future.

3.5 Self-Cleaning

Various options for an automated self-cleaning mechanism for ambulance were researched. Such a device would be quick, reducing the downtime for ambulances between emergency calls. Cleanitise is one of the many companies that produces equipment that deals with suitable cleaning. It is a disinfecting device that can be used in the hospital or ambulance setting. It operates by producing vapors that fill the patient compartment of the ambulance with disinfecting agent. According to the company, the vapors produced from Cleanitise are capable of accessing all surfaces and fixtures, killing surface bacteria and leaving the ambulance contaminant free.

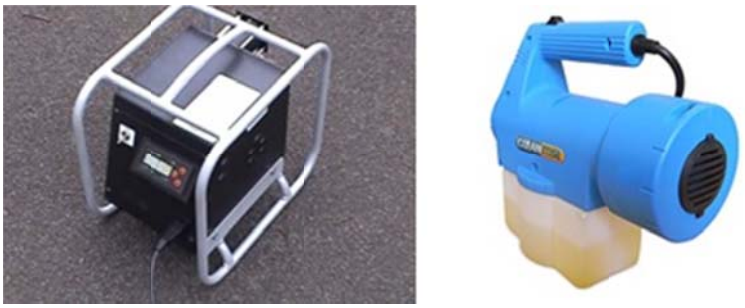


Figure 26 – Cleanitise Fogging Machine

The Cleanitise device, as seen in Figure 26, can be plugged in a regular 120V power supply and left on inside the ambulance for 7-10 minutes. After the fumigation is complete, all the doors and windows of the ambulance are opened for drying. The whole process takes from about 12 to 15 minutes. There are a few benefits and drawbacks for using Cleanitise. The advantages are that the system is portable, lightweight, small and easy to use. But the disadvantages of using the device are it cannot be used if there is no access to electricity, and is not portable enough to carry in the ambulance. Instead, it is a device that would remain at the station.

Figure 27 - Cleanitise Cleaning Process Demonstration

Figure 27 details a cleaning process using the vapor method. This project proposes to build a similar system that uses fogging but would be a permanent feature within the ambulance. A system of steel piping would connect spray nozzles to be positioned on the walls of the inside of the ambulance. Cleaning liquid would be poured into a small tank in the ambulance, which would then feed the spray nozzles by the help of a small pump. BEX Spray Nozzles is a manufacturer of spray systems that provide a complete spray assembly. The Assembly would be contained in a small 1.5ftx2ft box which can be mounted on the wall of the ambulance or attached to the floor.

The team recommends choosing an Air-Atomizing Nozzle. This is used to produce a fine spray of the disinfectant. Since the pressure of the liquid is high, the disinfectant would be able to reach corners, cracks and other inaccessible areas where a regular wipe cannot. The Nozzle we chose to investigate was a BEX JPL12 by BEX Spray Nozzles.

Figure 28 – Air Atomizing Nozzle

Figure 28 shows an air atomizing nozzle that could be implemented as a cleaning mechanism in the ambulance.

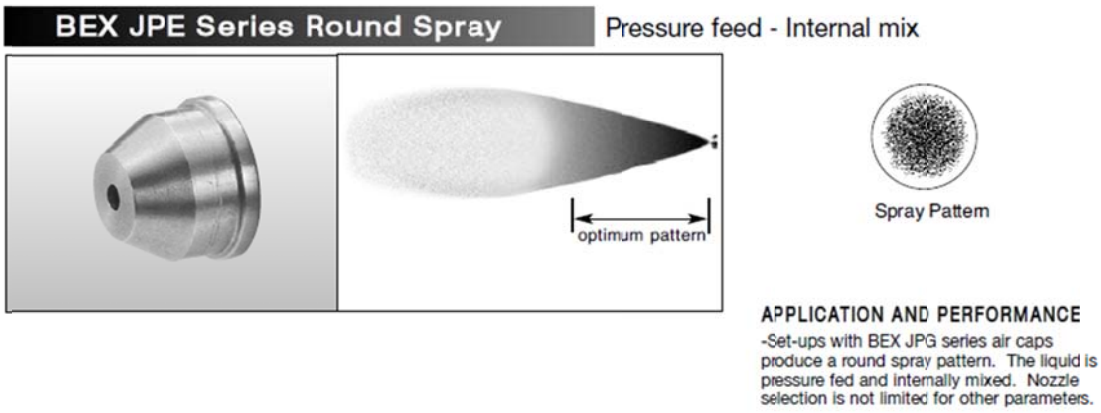


Figure 29 – BEX JPE Nozzle.

Figure 29 shows some of the specifications of the particular nozzle that was investigated. A price quote was provided by BEX Spray Nozzles for our assembly. The list of individual components with prices is given below.

Table 15 – Price Quotes

Component	Quantity	Price
BEX JPL 12 Nozzle	6	$300
Compressor	1	$350
Pump	1	$275
Pneumatic Filter	1	$100
Fluid pressure filter regulator	1	$95
Tubing	1	$150
Assorted fittings and brackets	1	$200
Air cylinder	1	$150
12V Battery	1	$150

Table 15 demonstrates that the components for a cleaning mechanism are not overly expensive.

Configuration of the nozzles is also very important. The positioning of the nozzles will vary from one ambulance to the other because of the different interior designs of each vehicle. Since this self-cleaning spray assembly will operate on high pressures, a total of six nozzles would be optimum for the ambulance.

The total cost of the Self-Cleaning Spray mechanism would be approximately $1800. Although this system has a high installation costs, the cost of maintenance would be substantially lower because of short operation times. Furthermore, maintenance costs would entail the occasional purchase of refilling the compressed-air cylinder and disinfectant solution.

A CAD model of the ambulance was made with an interior design similar to the ambulance visited at Worcester Emergency Medical Services. The spray assembly is colored red in the CAD model. The drawing is shown below with the walls of the ambulance hidden.

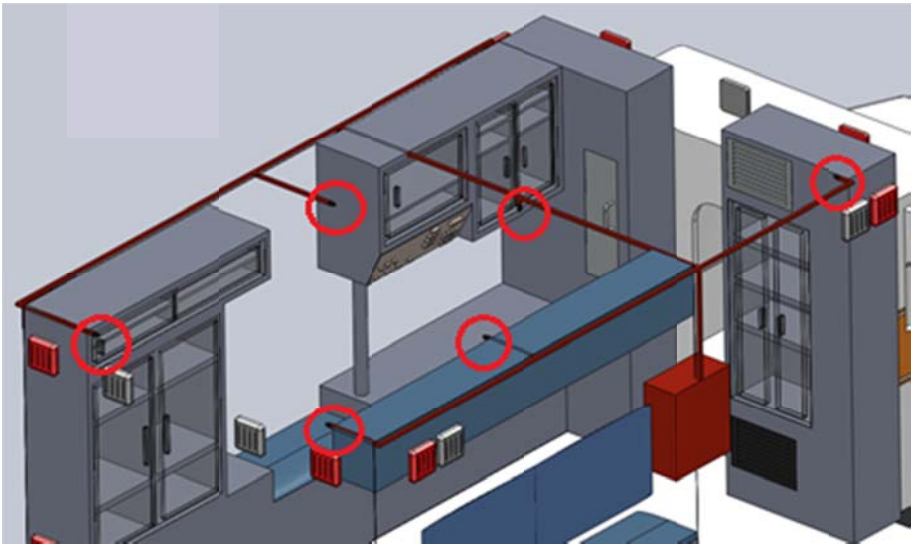


Figure 30 – Spray Nozzle Placements

Figure 30 details possible placement for nozzles in the ambulance. Figure 31 shows a close-up of a spray nozzle, as designed in the CAD model.

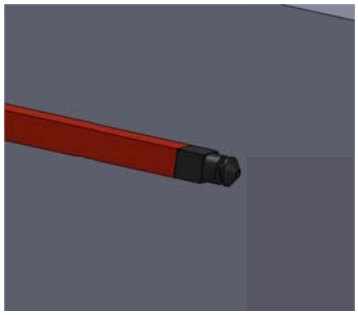


Figure 31 – Spray Nozzle

The placement of the nozzles in the above configuration will make sure that the disinfectant solution reaches all the surfaces of the ambulance. This method of cleaning is suitable for the

ambulance since it potentially can get rid of any bloodborne or airborne pathogens present inside the ambulance. The spray should be able to reach all the surfaces and kill any bacteria that might spread to patients through surface contact. Also, airborne pathogens present inside the ambulance are removed due to the aerosolized disinfecting solution by air atomizing nozzles.

For the self-cleaning mechanism, it was proposed that a drainage system also be implemented in the ambulance. Current ambulances lack a proper drainage system and any fluid remains on the floor of the ambulance until cleaned. This contaminates the ambulance floor spreading germs and bacteria across surfaces even where there was no spillage. The fluid usually collects in the step on the side door which drains onto the road.

For the proposed drainage system, the floor would have small slots cut into it with a mesh covering it. This would only let fluid pass through and would prevent any other material from entering the drain. Depending on the size of the ambulance, anywhere from two to four small sections of the floor could be cut. These cuts would be connected together by aluminum piping which would all drain into a disposable container.

A CAD model was made for the drainage system which is shown below in Figure 32. Figure 33 shows the drains from an alternate top view.

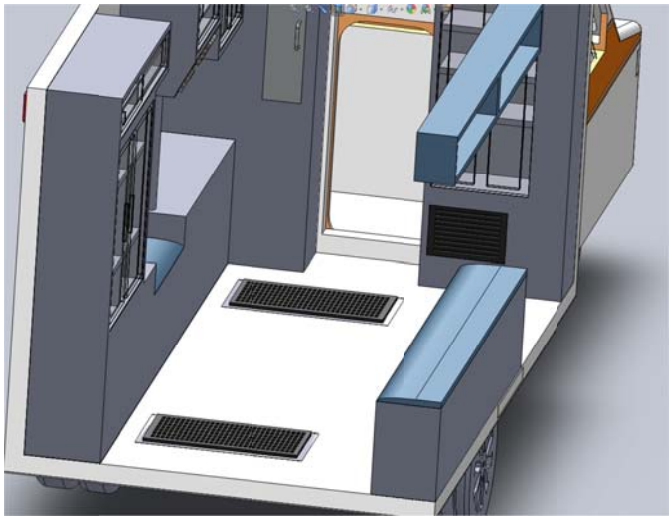


Figure 32 – Floor Drains

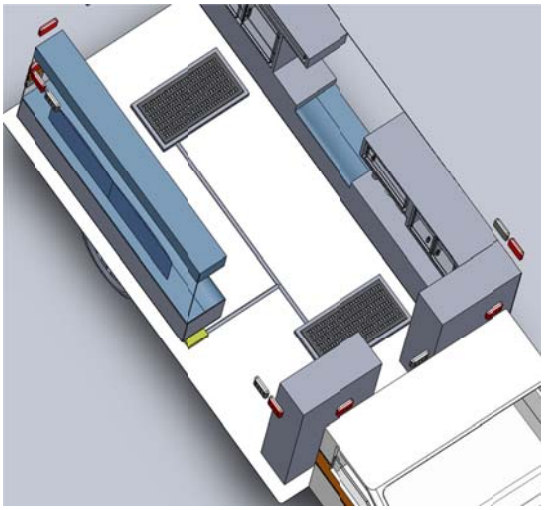


Figure 33 – Drainage System Top View

A complete drainage system with drain pipes and a collection chamber can be seen in the above figures. Our recommendation is to build a similar drainage system within the ambulance which will drain all fluids out of the floor of the ambulance and quickly provide the ambulance workers and patients a contaminant free environment.

CHAPTER 4. CONCLUSION

4. Introduction

Significant advancements have been made in the field of Emergency Medical Service in the past, such as proper procedures for patient care, federal guidelines for ambulance design, and unified standards for pre-hospital emergency care. However, due to the increasing number of ambulance dispatches in recent years, conventional cleaning protocols and personal protective equipment are no longer adequate or sufficient to protect emergency responders and transported patients from various types of infectious diseases. Therefore, the major objectives for our Interactive Qualifying Project are to (1) research and recommend designs for better body substance isolation systems that could prevent the spread of pathogenic particles in an ambulance setting, and to (2) recommend new cleaning procedures with the use of alternative decontamination equipment that could dramatically reduce ambulance downtime between dispatches. When evaluating the viability of the engineering solutions proposed by the team, a number of constraints emerged, such as the cost, and interior placement for the recommended equipment. Without presenting major modifications to the interior layout of an ambulance, the team strived to achieve the project objectives with minimum cost of purchase, installation, and maintenance for the proposed isolation systems and decontamination equipment.

The IQP team started off the project with an intensive background research in all possible contaminants that could be present in an ambulance setting. The two major groups included are the bloodborne pathogens and the airborne pathogens. The IQP team conducted a detailed research in the modes of transmission of these pathogens and the diseases that they can spread. We also investigated which chemical agents are recommended to clean the ambulance, and how to protect the ambulance workers and patients from becoming infected. This data obtained was

then used to look for any available products that would remove the specific contaminants from the inside of the ambulance.

In order to enhance cleaning procedures for the ambulance, current cleaning methods were investigated. A visit was made to the Worcester Emergency Medical Services to learn of the methods and procedures they use for ambulance cleaning. It was established that the current cleaning procedures are time-consuming and can be improved since there are no standard procedures laid out. Project goals were then decided and a comprehensive study was conducted to find the cheapest and most effective method of ambulance decontamination that would dramatically reduce ambulance downtime.

Four different products were researched: UVGIs, air filters, biosensors, and the self cleaning mechanism. For many of the products, their specifications were listed and their efficiency in removing the pathogens was calculated. Data indicated that UVGIs have high efficiency in removing pathogens from both the surface and the air. The efficacy of UVGI for airborne pathogens might increase with the use of HEPA air filter, however no specific HEPA filtration products were found. Lastly, it was concluded that although biosensors were a promising technology for effective measurement of pathogens, currently they are very expensive and more research needs to be conducted to be able to use in an ambulance setting.

As far as the theoretical self cleaning mechanism is considered, it is a relatively cheap and very quick way to flood the insides of the ambulance with a disinfectant spray which would neutralize most airborne pathogens and clean out almost all surface contaminants. The major drawbacks of such a system were its energy consumption and its ability to leave residue after its use. If the self-cleaning mechanism is used with the air filtration system, the issue might be resolved, yet the power issue might have to be solved with an additional battery.

As a whole, the recommendations provided by the IQP team are believed to provide significant improvements to what is currently available. Integrating the products studied in the project would possibly be an effective method to decontaminate the inside of an ambulance. Since such devices are relatively fast, it would potentially reduce ambulance downtime between dispatches, therefore meeting both goals of our project.

However the consideration of different ambulance designs, materials and maintenance systems are solely not enough to reduce contamination threats. Equipment used in the ambulance, such as stretchers, stair-chairs and backboards are all victims of contamination and carriers of pathogens. It is therefore important to stress the importance of contamination issues in the pre-hospital care to EMS equipment manufactures, as presented to Stryker (see Appendix I), a medical technology firm based in Kalamazoo, Michigan.

There were several limitations to this project, such as having access to only free journal articles. When we were conducting our background research using scientific literature, we only had access to articles that were free to read online or were available through the university. Also, we only examined UVGI devices from a couple manufacturers – a limitation that might not give us a clear general picture of what exists on the market today. In addition, the estimates we made regarding specifications not given for some of these UVGI devices might have been inaccurate or overly simplistic. For the CAD model in the self-cleaning mechanism, the design constructed was based mainly off of what we thought would provide adequate cleaning – testing would be needed. And even then, extensive research into power or size constraints would be needed. Finally, the majority of the work done for this project was purely theoretical – actual testing should be done in the ambulance setting to truly investigate viability.

Future work for this project might involve attempts to resolve the limitations experienced here. For example, comparisons might be made between more than two UVGI device manufacturers. Or, actual testing might be conducted, such as testing UVGI in an actual ambulance, or constructing a prototype of the cleaning mechanism in an ambulance. Also, further work that might be done on this project may include looking into other recommendations to prevent contamination in the ambulance, such as looking into materials that actively discourage the growth or survival of microorganisms on its surfaces.

APPENDICIES

Appendix A – Levels of Care and Certifications

Certification	Level of Care	Examples of Care Given
First Responder	Basic Life Support	CPR, AED, splinting, oxygen administration, artificial ventilation via Bag Valve Mask (BVM), Oralpharyngeal Airway (OPA) or Nasalpharyngeal Airway (NPA) Intubation, and assistance with a limited number of drugs.
EMT-Basic	Basic Life Support	CPR, AED, splinting, traction splinting, oxygen administration, artificial ventilation via Bag Valve Mask (BVM), Oralpharyngeal Airway (OPA) or Nasalpharyngeal Airway (NPA) Intubation, and assistance with a limited number of drugs.
EMT-Intermediate	Advanced Life Support	CPR, AED, splinting, traction

		splinting, oxygen administration, artificial ventilation via Bag Valve Mask (BVM), Oralpharyngeal Airway (OPA) or Nasalpharyngeal Airway (NPA) Intubation, IV therapy preparation, manual defibrillation, cardiac rhythm interpretation, and orotracheal intubation and assistance with certain drugs.
EMT-Paramedic	Advanced Life Support	CPR, AED, splinting, traction splinting, oxygen administration, artificial ventilation via Bag Valve Mask (BVM), Oralpharyngeal Airway (OPA) or Nasalpharyngeal Airway (NPA) Intubation, IV therapy preparation, manual defibrillation, cardiac rhythm interpretation, and orotracheal

	intubation, needle cricothyroidotomy, needle decompression for tension pneumothorax and many medication therapies.

Appendix B – UVGI Lamp Specifications

Lamp Length	Lamp Model	Lamp Description	Type UV Lamps	Lamp Base	UV Output	UV Intensity µW/cm² @1m
6"	GML370	Hot Cathode Lamp	PL-S9W/TUV	PL-S	2.4W UV	-
	GML180	Hot Cathode Lamp	G 4T5	T5/mini bi-pin	0.5W UV	5.4
	GML170	Hot Cathode Lamp	OZ4T5	T5/mini bi-pin	0.5W UV	5.4
9"	GML195	Hot Cathode Lamp	G 6T5	T5/mini bi-pin	1.0W UV	11
	GML190	Hot Cathode Lamp	OZ 6T5	T5/mini bi-pin	1.1W UV	11
12"	GML205	Hot Cathode Lamp	G 8T5	T5/mini bi-pin	1.6W UV	17
	GML125	Slimline Lamp	G12T5-1/2L/BP	T5/mini bi-pin	6.0W UV	66
	GML075	Slimline Lamp	G12T5-1/2VH/BP	T5/mini bi-pin	6.0W UV	66
	GML405	High Output Lamp	GPH357T5L/HO	Four-pin	8.5W UV	92
14"	AAWHO/14	High Output Lamp	GML600	Four-pin	12W UV	106
	UV Bulb HO	High Output Lamp	UVHOAL300AV/14	Four-pin	12W UV	106
16"	GML020	Cold Cathode Lamp	782 L 10	T5/single-pin	2.8W UV	28
	GML120	Cold Cathode Lamp	782 VH 10	T5/single-pin	2.8W UV	28
	GML060	Slimline Lamp	G10T5-1/2L	T5/single-pin	5.3W UV	55
	GML350	Slimline Lamp	G10T5-1/2L-4P	T5/four-pin	5.3W UV	55
	GML070	Slimline Lamp	G10T5-1/2VH	T5/single-pin	5.3W UV	55
	GML430	High Output Lamp	GSL406T5L/HO	Four-pin	10.0W UV	108
18"	GML210	Hot Cathode	G15T8	T8/medium	3.6W	38

		Lamp		bi-pin	UV	
	TUV15T8*	Germicidal	G15T8	T8/medium bi-pin	3.6W UV	38
	GML215	Hot Cathode Lamp	G25T8	T8/medium bi-pin	5.0W UV	54
	GML410	High Output Lamp	GSL406T5L/HO	Single-pin	10.0W UV	100
22"	HOAL/22	High Output Lamp	GPH550T5/HO	Four-pin	18.1W UV	174
24"	GML435	High Output Lamp	GPH610T5L/HO	Four-pin	16.2W UV	175
27"	GML025	Cold Cathode Lamp	782 L 20	T5/single-pin	5.5W UV	52
	GML290	Cold Cathode Lamp	782 VH 20	T5/single-pin	5.5W UV	52
	GML325	Slimline Lamp	GSL591	T5/single-pin	-	-
	GML355	Slimline Lamp	S24T5-4P	T5/four-pin	-	-
	GML415	High Output Lamp	GSL610T5L/HO	Single-pin	16.2W UV	140
30"	GML030	Cold Cathode Lamp	782 L 25½	T5/single-pin	7.3W UV	75
36"	GML010	Cold Cathode Lamp	782 L 30	T5/single-pin	8.3W UV	73
	GML035	Cold Cathode Lamp	782 VH 29	T5/mini bi-pin	9.1W UV	80
	GML040	Cold Cathode Lamp	782 VH 30	T5/single-pin	5.2/8.3W UV	46 / 73
	GML220	Hot Cathode Lamp	G30T8	T8/medium bi-pin	8.3W UV	85
	GML005	Slimline Lamp	G36T6L	T5/single-pin	13.8W UV	120
	GML100	Slimline Lamp	G36T6L-4P	T5/four-pin	12.7W UV	110
	GML090	Slimline Lamp	G36T6VH	T5/single-pin	13.8W UV	120
	GML095	Slimline Lamp	G37T6VH	T5/single-pin	15.2W UV	124
	GML420	High Output	GSL843T5L/HO	Single pin	25.0W	195

		Lamp			UV	
	GML440	High Output Lamp	GSL843T5L/HO/4	Four-pin	25.0W UV	195
48"	GML425	High Output Lamp	GSL1148T5L/HO	Single pin	36.1W UV	250
	GML445	High Output Lamp	GSL1148T5L/HO/4	Four-pin	36.1W UV	250
60"	SLR32143	HO Amalgam Lamp	TUV 260W XPTDIM	Four-pin	93W UVC	650
	SLR32143 HP	HO Amalgam Lamp	TUV335WXPT	Four-pin	93W UVC	650
61"	GA64T6	HO Amalgam Lamp	GIA1564T6LCA	Two-step, 4-pin	75W UVC	600
	G64T5L	UV Lamp	TUV64T52PSE	4-pin		
64"	GML017	High Output Lamp	GXO64T5L H/O	Single-pin	46.0W UV	370
	GML015	Slimline Lamp	G64T5L	T5/single-pin	26.7W UV	190
	GML140	Slimline Lamp	G64T5VH	T5/single-pin	26.7W UV	190
	GML270	Slimline Lamp	G64T5L-4P	T5/four-pin	26.7W UV	190

* Philips 15W, Sterilamp® T-8 Fluorescent Lamp, Medium Bi-pin Base. Germicidal UV-C for air disinfection applications. Compatible: Ionic Breeze GP UV air purifier.

Table obtained from American Air and Water, Inc. (http://www.americanairandwater.com/uv-lamps.htm)

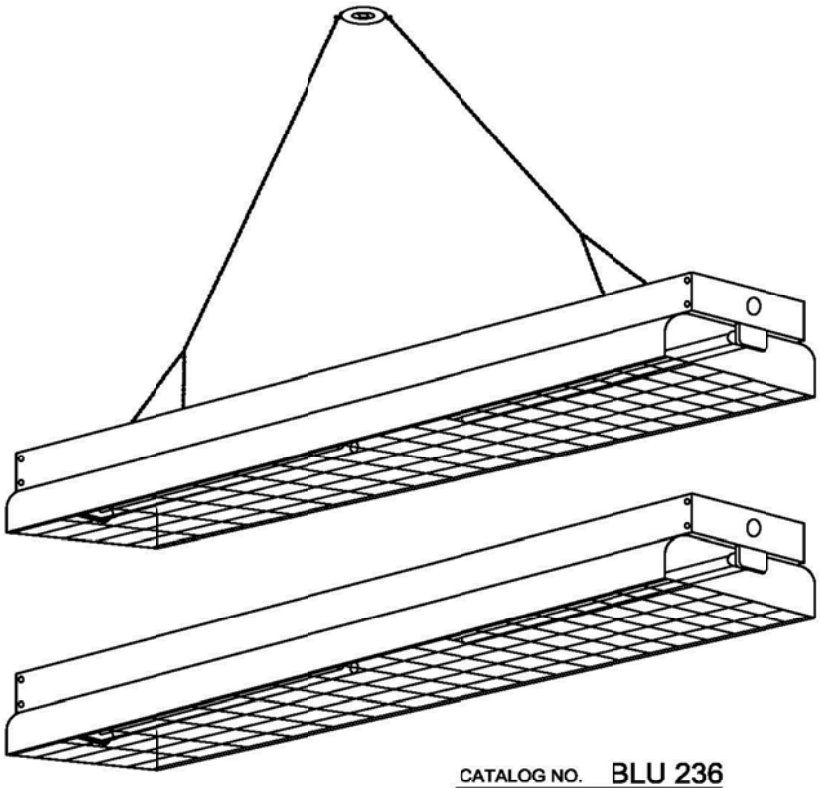
Appendix C – UV Dosage Table

Organisms:	Energy Dosage of Ultraviolet radiation (UV dose) in μWs/cm^2 needed for kill factor	
Bacteria	90% (1 log reduction)	99% (2 log reduction)
Bacillus anthracis - Anthrax	4,520	8,700
Bacillus anthracis spores - Anthrax spores	24,320	46,200
Bacillus magaterium sp. (spores)	2,730	5,200
Bacillus magaterium sp. (veg.)	1,300	2,500
Bacillus paratyphusus	3,200	6,100
Bacillus subtilis spores	11,600	22,000
Bacillus subtilis	5,800	11,000
Clostridium tetani	13,000	22,000
Corynebacterium diphtheriae	3,370	6,510
Ebertelia typhosa	2,140	4,100
Escherichia coli	3,000	6,600
Leptospiracanicola - infectious Jaundice	3,150	6,000
Micrococcus candidus	6,050	12,300
Micrococcus sphaeroides	1,000	15,400
Mycobacterium tuberculosis	6,200	10,000
Neisseria catarrhalis	4,400	8,500
Phytomonas tumefaciens	4,400	8,000
Proteus vulgaris	3,000	6,600
Pseudomonas aeruginosa	5,500	10,500
Pseudomonas fluorescens	3,500	6,600
Salmonella enteritidis	4,000	7,600
Salmonela paratyphi - Enteric fever	3,200	6,100
Salmonella typhosa - Typhoid fever	2,150	4,100
Salmonella typhimurium	8,000	15,200
Sarcina lutea	19,700	26,400
Serratia marcescens	2,420	6,160
Shigella dyseteriae - Dysentery	2,200	4,200
Shigella flexneri - Dysentery	1,700	3,400
Shigella paradysenteriae	1,680	3,400
Spirillum rubrum	4,400	6,160
Staphylococcus albus	1,840	5,720
Staphylococcus aureus	2,600	6,600

Staphylococcus hemolyticus	2,160	5,500
Staphylococcus lactis	6,150	8,800
Streptococcus viridans	2,000	3,800
Vibrio comma - Cholera	3,375	6,500
Molds	90%	99%
Aspergillius flavus	60,000	99,000
Aspergillius glaucus	44,000	88,000
Aspergillius niger	132,000	330,000
Mucor racemosus A	17,000	35,200
Mucor racemosus B	17,000	35,200
Oospora lactis	5,000	11,000
Penicillium expansum	13,000	22,000
Penicillium roqueforti	13,000	26,400
Penicillium digitatum	44,000	88,000
Rhisopus nigricans	111,000	220,000
Protozoa	90%	99%
Chlorella Vulgaris	13,000	22,000
Nematode Eggs	45,000	92,000
Paramecium	11,000	20,000
Virus	90%	99%
Bacteriopfage - E. Coli	2,600	6,600
Infectious Hepatitis	5,800	8,000
Influenza	3,400	6,600
Poliovirus - Poliomyelitis	3,150	6,600
Tobacco mosaic	240,000	440,000
Yeast	90%	99%
Brewer's yeast	3,300	6,600
Common yeast cake	6,000	13,200
Saccharomyces carevisiae	6,000	13,200
Saccharomyces ellipsoideus	6,000	13,200
Saccharomyces spores	8,000	17,600

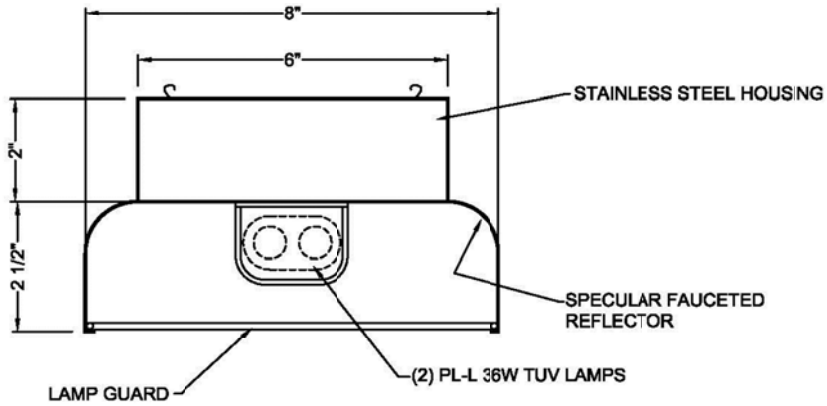
Table obtained from American Air and Water, Inc.
(http://www.americanairandwater.com/uv-facts/uv-dosage.htm)

Appendix D – UVGI Product Specifications



CATALOG NO. BLU 236

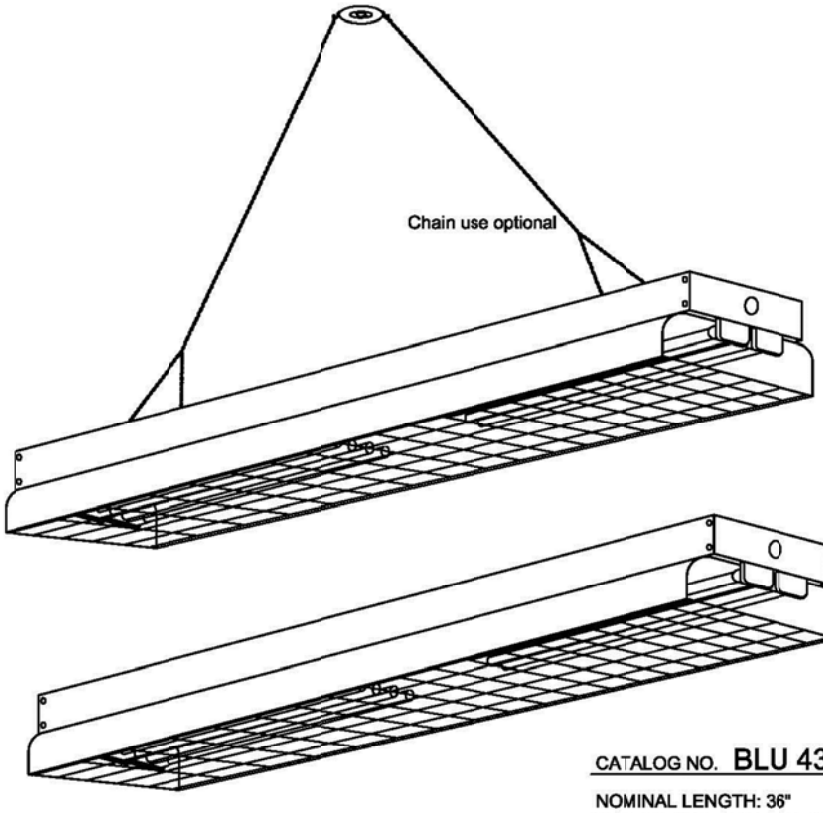
NOMINAL LENGTH: 36"
LAMPING: (2) PL-L 36W TUV (120V)
UV WATTS: 24UVW
NOMINAL WATTS: 72W



5/6/05

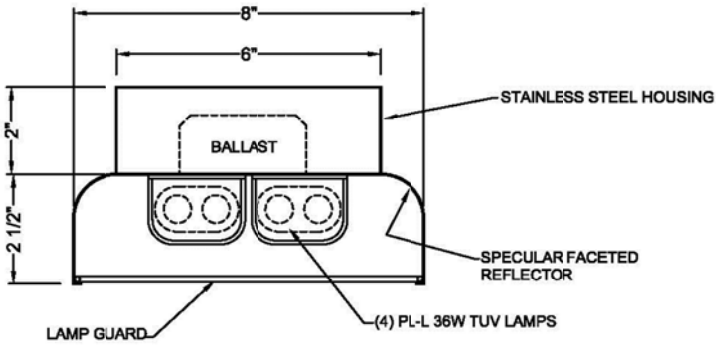
DATA SHEET
BLU 236

LUMALIER
UV AIR & SURFACE DISINFECTION
743 S. DUDLEY ST. MEMPHIS, TN 38104 800-774-5799
www.LUMALIER.com EPA # 86538-TN-001 Fax: 901-946-2478



CATALOG NO. **BLU 436**

NOMINAL LENGTH: 36"
LAMPING: (4) PL-L 36W TUV (120V thru 277V)
UV WATTS: 48 UVW
NOMINAL WATTS: 144 W



5/6/05

DATA SHEET
BLU 436

LUMALIER
UV AIR & SURFACE DISINFECTION
743 S. DUDLEY ST. MEMPHIS, TN 38104 800-774-5799
www.LUMALIER.com EPA # 86538-TN-001 Fax: 901-946-2478

AMERICAN AIR & WATER®, INC.

AAW Handheld Ultraviolet Germicidal System

The AAW Handheld UV wand is a portable direct germicidal UV system for surface disinfection. It can help control the growth of germs such as viruses, bacteria, mold and mold spores and reduce spreading of infections.

AAW Handheld Specs	
Lamp #	SBL350T
Lamp Life	17,000 hours
Lamp Intensity at 6"	>735µW/cm²
UV Dose /1 min at 6"	>44,000µW-sec/cm²
Size	18"L x 5"W x 6.25"H
Weight	5lbs

AAW Handheld UV wand is a portable system for applications where a permanent UVC installation is not desired or needed. The UV system can help reduce or eliminate microbial contamination in spaces that do not need constant exposure to UVC light. Common environments include laboratories, hospitals and food plants. The High Output UV lamp emits high intensity UV so the system should be positioned in a way to avoid exposing people to direct or reflected UV light.

Each Handheld UV disinfection system features:

- On/off switch
- Safety glasses
- Tool-free lamp change
- 14" high output shatterproof lamp
- 6' three-prong power cord
- Oversized handle
- Spectrally polished reflector
- 120-277V, 50/60Hz
- One year prorated warranty on the UV lamp
- Five-year, non-prorated warranty on the chassis

Refer to the attached UV dose sheet. Divide the desired UV dose by the lamp intensity to calculate the exposure time in seconds. Note: the UV intensity is higher if you place the unit closer to the surface. At 2" the intensity will be 2.5 times higher.
Example: UV dose of 6,600µWs/cm² is needed for 99% inactivation of e. coli. 6,600 / 735 = 8.9 sec.

The UV lamp must be replaced before the end of effective lamp life. Lamps will continue to operate after that but 254nm UV is not emitted. Always unplug the power cord before replacing the lamp. When installing the UV lamp or relamping use cotton gloves or make sure not to touch the lamp. Fingerprints on the glass portion of the germicidal UV lamp will reduce the ultraviolet output.

Benefits of AAW Handheld germicidal UV wand:

- Improves the indoor environment by reducing surface and airborne bacteria, viruses, mold and spores
- Reduces the risk of transmission of cold, flu, TB and other illnesses
- Reduces the irradiation time by using a high output UV lamp and spectrally polished reflector
- Produces no ozone or any other secondary contaminants

AAW Handheld Price

Model	Description	List Price
AAW Handheld	Direct handheld germicidal UV system with a shatterproof High Output UV lamp, reflector, on/off switch and ergonomic handle	$400
	Replacement Parts	
SBL350T	High output germicidal UV lamp with shatterproof coating	$115

American Air & Water®, Inc. * 12 Gibson Drive * Hilton Head Island, SC 29926
Phone: 843-785-8699 * 888-378-4892 * Fax: 843-785-2064 * www.americanairandwater.com

AMERICAN AIR & WATER®, INC.

AAW-TBE-14-1 IN-ROOM ULTRAVIOLET GERMICIDAL SYSTEM

The AAW-TBE-14-1 is a totally enclosed air-movement germicidal UV system for in-room control of airborne TB and flu, as well as other airborne viruses, bacteria and mold.

AAW-TBE-14-1 UV System	
Lamp #	AAWHO/14
Lamp Life	12,000 hours
Lamp Intensity	550µW/cm² at 1 foot
Single-pass UV Dose	1,645µWsec/cm²
Air Movement	35CFM
Electrical	120/220V, 50/60Hz, 1Amp
Construction	430 Stainless Steel

AAW-TBE-14-1 is designed to be portable or wall-mounted to reduce airborne microbiological contamination. The system features stainless steel chassis, pull-chain switch, power cord, a fan and two filters. The High Output UV lamp is completely enclosed so the system can be on at all times protecting personnel and providing maximum germicidal irradiation. Re-lamping requires only disconnecting the power and opening the top cover.

AAW-TBE-14-1 fixtures are shipped assembled with the lamp packed separately inside the unit to prevent breakage.

AAW-TBE-14-1 mounts via two keyhole slots in the back of the unit. These holes are on 12.5" center and require # 8 anchor screws.

BALLAST: The UL listed solid-state electronic ballast is a Class P rapid start with a power factor minimum of .95. It is available for 120V 60Hz and is designed to maximize photon production in air temperatures of 35° to 175° F. Ballasts have an RFI - EMI rating as defined by FCC part 18A for industrial / commercial applications in regards to suppression.

The UV lamp must be replaced before the end of effective lamp life. Lamps will continue to operate after that, however 254 nm output is not emitted. When installing the UV lamp or relamping use cotton gloves or make sure not to touch the lamp. Fingerprints on the germicidal UV lamp will reduce the ultraviolet output. Check the filters regularly and clean or replace as needed.

Features and Benefits of AAW-TBE-14-1 germicidal UV system:

- Improves Indoor Air Quality (IAQ) by reducing airborne bacteria, viruses, mold and spores
- Reduces the risk of airborne transmission of cold, flu, TB and other illnesses
- High output UV lamp
- Five-year, non-prorated warranty on the chassis
- One year prorated warranty on the UV lamp
- Produces no ozone or any other secondary contaminants

AAW-TBE-14-1 PARTS

Model	Description
AAW-TBE-14-1	Enclosed stainless steel fixture with High Output UV lamp, fan and 2 filters
	Replacement Parts
AAWFLT014	Filter 4.75" x 4.13" x 0.75" – two per unit
AAWHO/14	High output germicidal UV lamp
AAWFAN014	35CFM Fan
AAW350	Electronic ballast TXG350

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MRS MOBILE ROOM STERILIZERS SPECS & PRICES

Model **MRS3684P**

These mobile 8-lamp UV sterilizers feature 2-minute "ON" delay and 24-hour timer for total room irradiation. They are designed for operating rooms, sterile areas, laboratories, unoccupied patient rooms, clean rooms and all other applications where permanent fixtures are not practical. Each unit is equipped with casters for maximum portability.

Dimensions - 20"L x 20"W x 48"H

Installation Instructions:

These units are shipped assembled and wired for 120V, 60Hz operation. The only procedure necessary is installation of the eight 4-pin **GML100** germicidal lamps.

To install the lamps remove the top thumb screw and slide the lamp into 4-pin connector. Use gloves when touching the lamp. If fingerprints get on the lamp, clean the lamp with denatured alcohol prior to operation.

General Operation:

1. Position unit in center of area to be exposed to UV rays
2. Plug unit into 120V, 60Hz outlet
3. Set 24-hour timer for desired exposure time
4. Push "On" button - 2 minute delay switch
5. Leave area or utilize protective glasses. Avoid exposure to direct or reflected UV light
6. Check and clean lamps regularly - annual replacement required if used continuously - 12,000 hours rated life.

Model	Description
Mobile Room sterilizer with 24 hour timer, 2-minute "ON" delay, casters, and handle (20"L x 20"W x 48"H)	
MRS3684P	Eight GML100 lamps 120V, 60Hz
MRS3684P/220	Eight GML100 lamps 220V, 50/60Hz
MRS3684P/SS	Stainless steel Mobile unit with 8 GML100 lamps 120V
GML100	Replacement lamp
TXG015B	Replacement ballast

Warning: Care should be taken to insure that personnel are not exposed to direct or reflected UV light. Suitable eye and skin protection should be employed when lamp is in operation. Before cleaning or relamping, always turn the power OFF.

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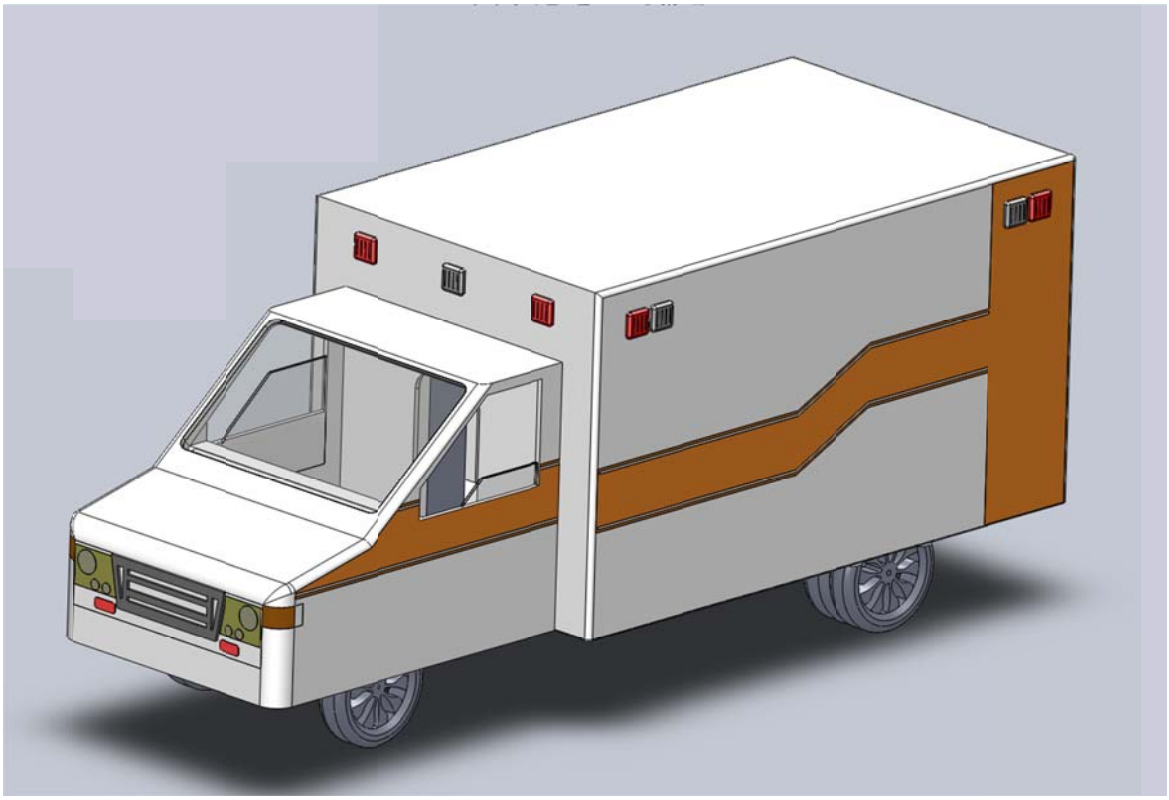
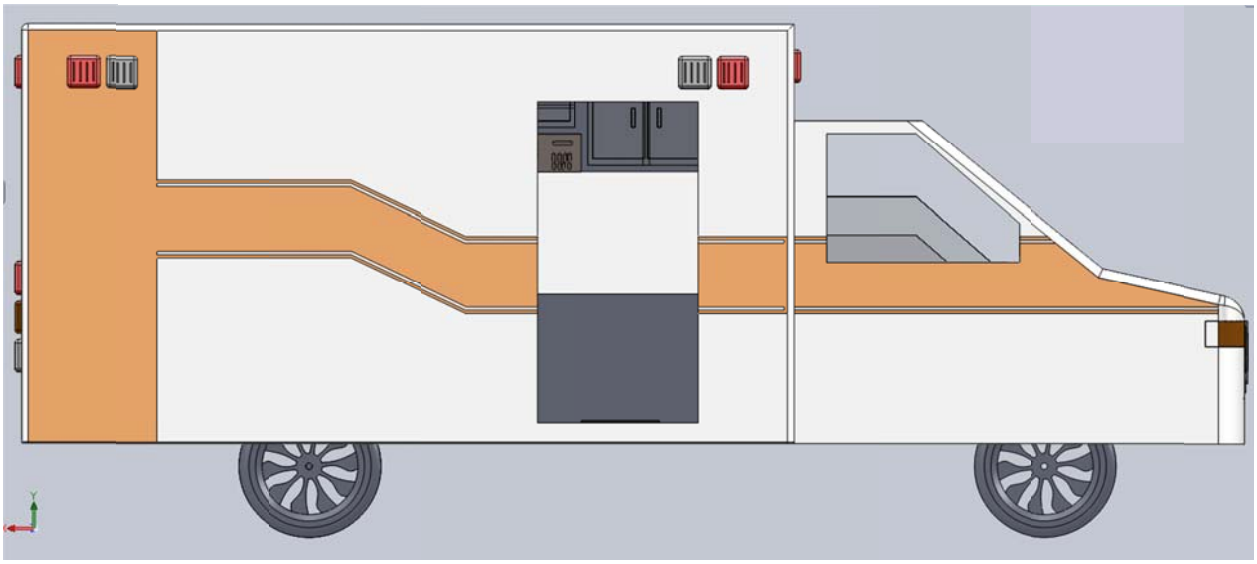
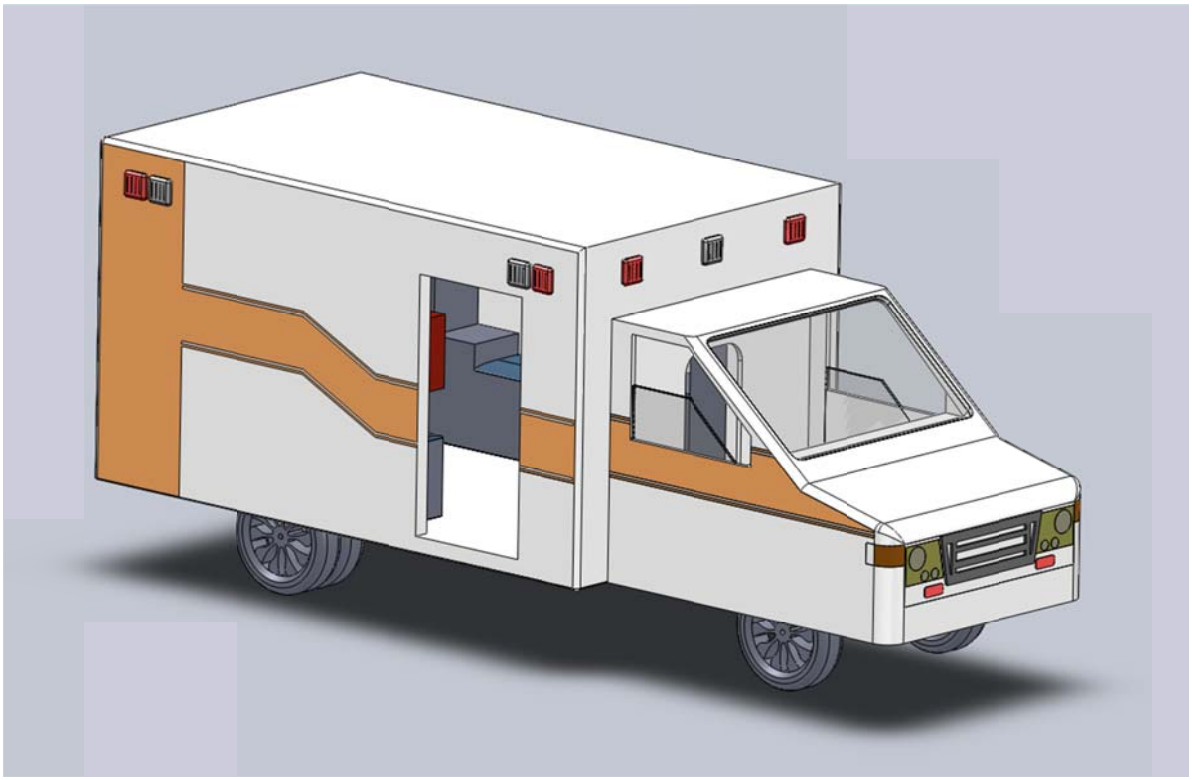
Appendix E – Ambulance CAD Drawing based on Federal Specifications



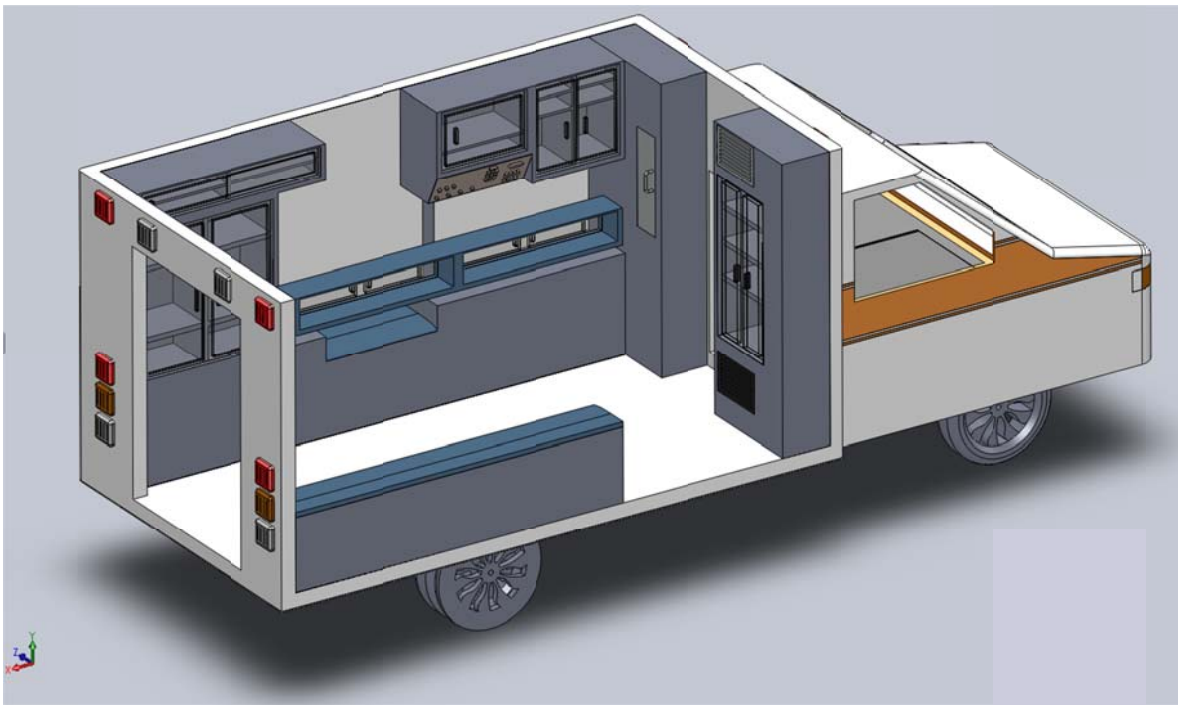
Isometric View



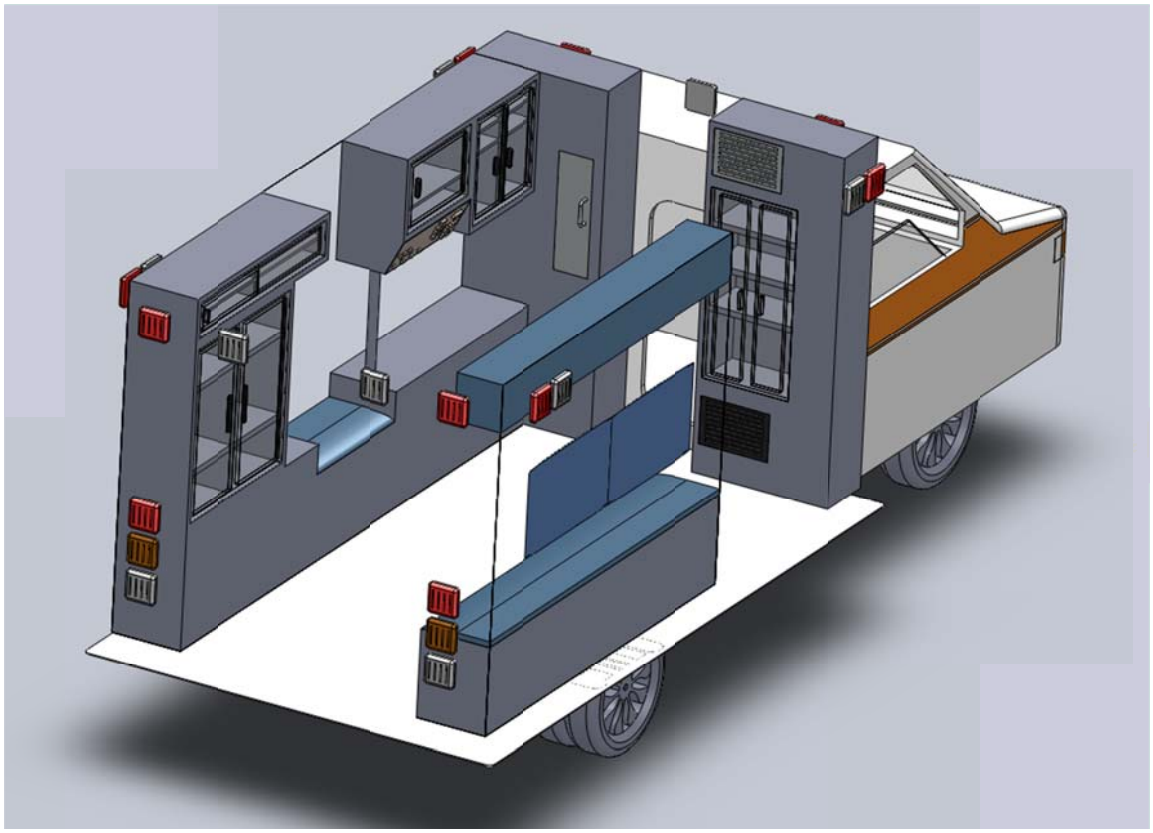
Side View



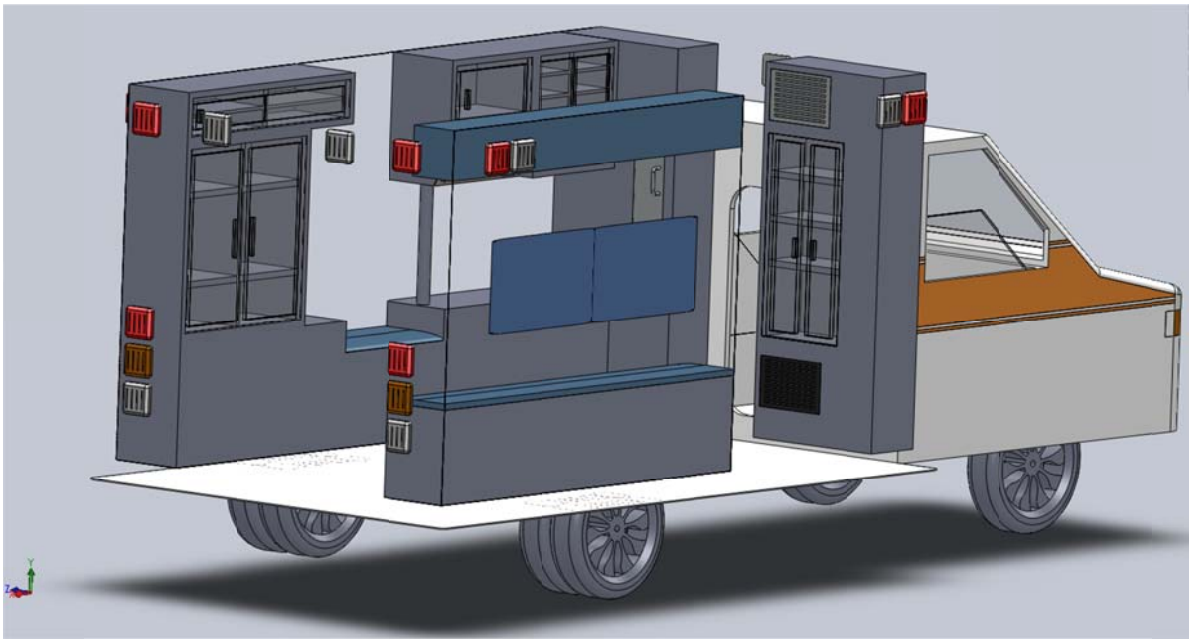
Alternate Exterior View



Interior View

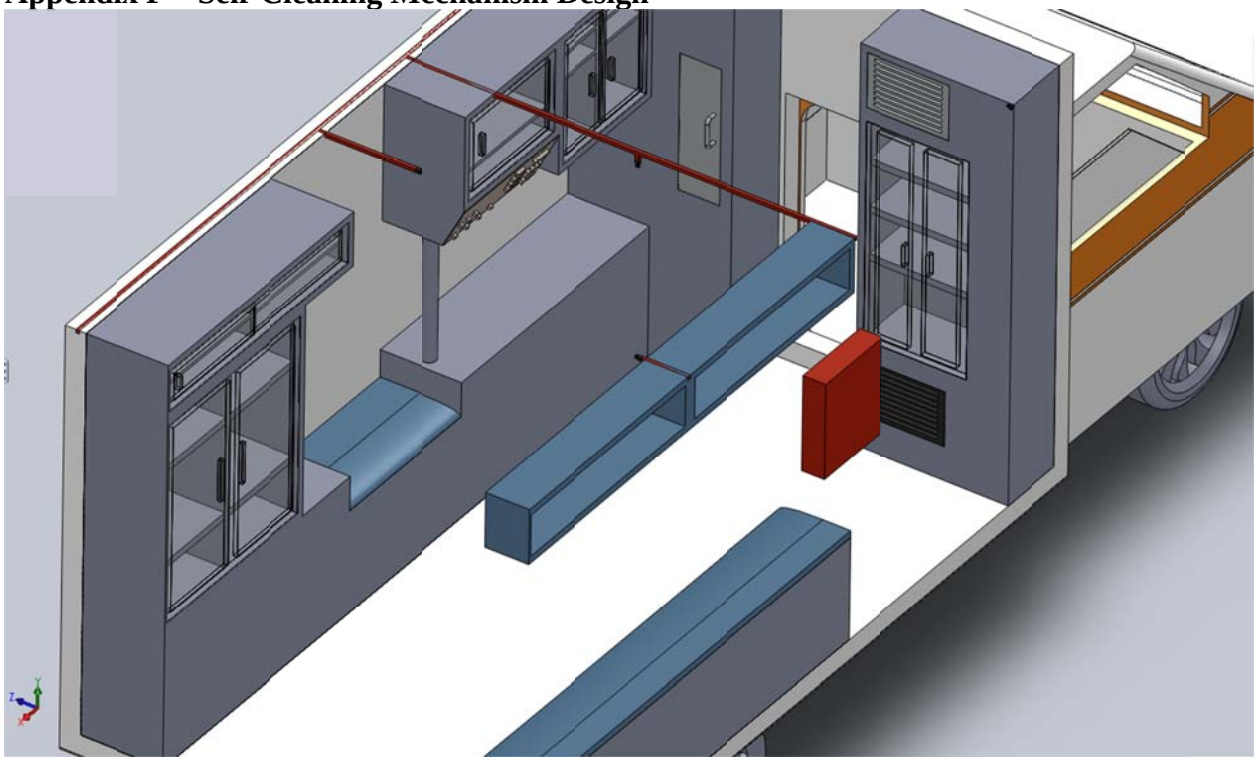


Rear Interior View



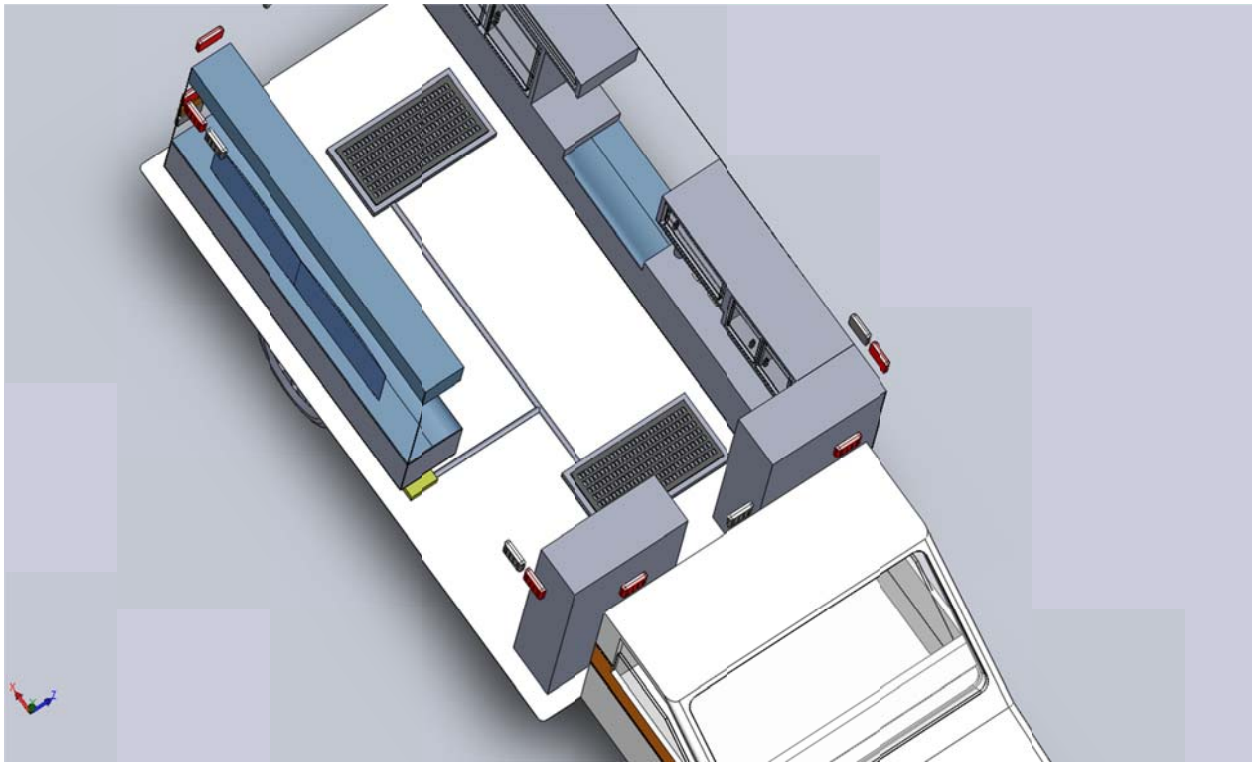
Alternate Rear Interior View

Appendix F – Self-Cleaning Mechanism Design

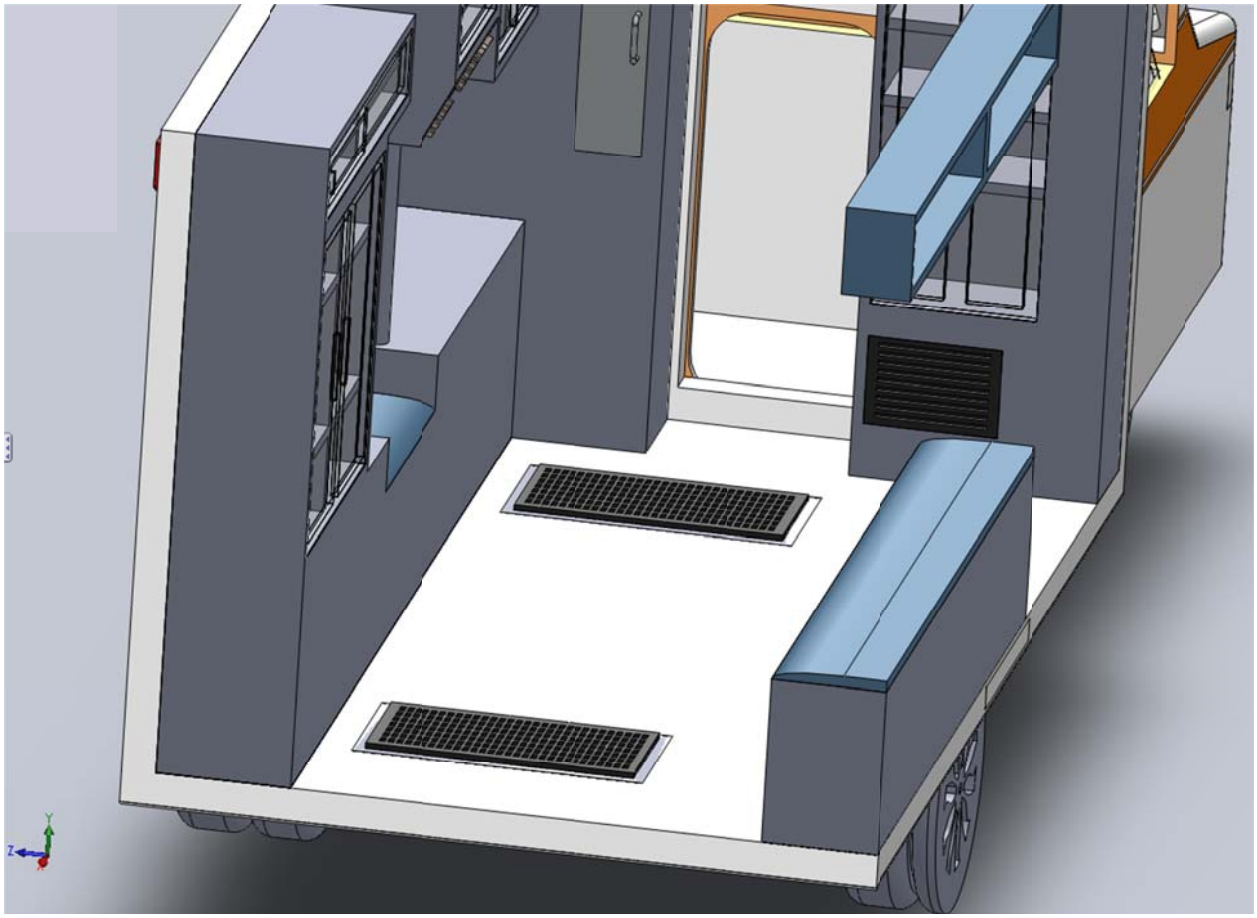


Self-Cleaning System

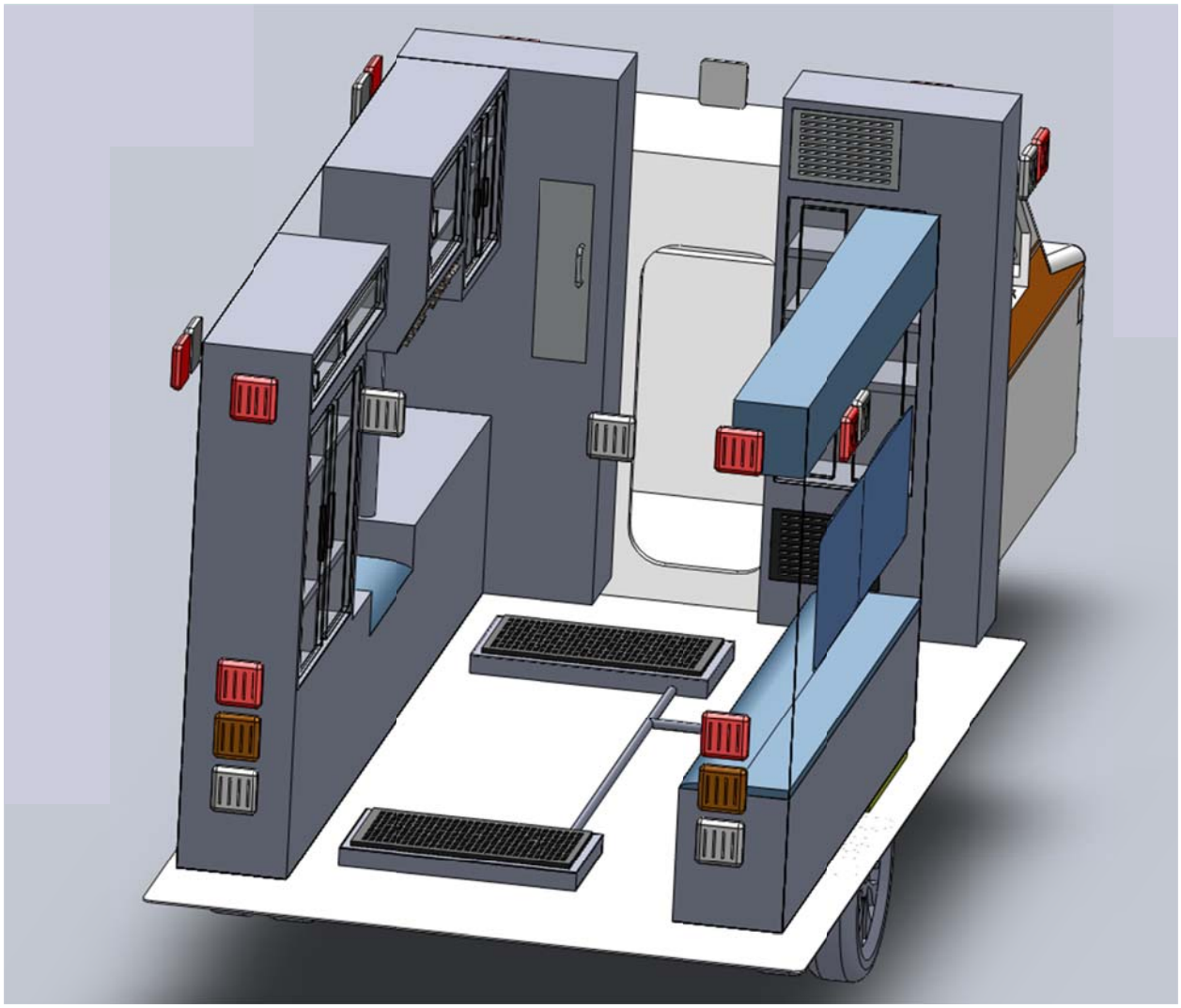
Appendix G – Drainage System Design



Drainage System with Piping Exposed

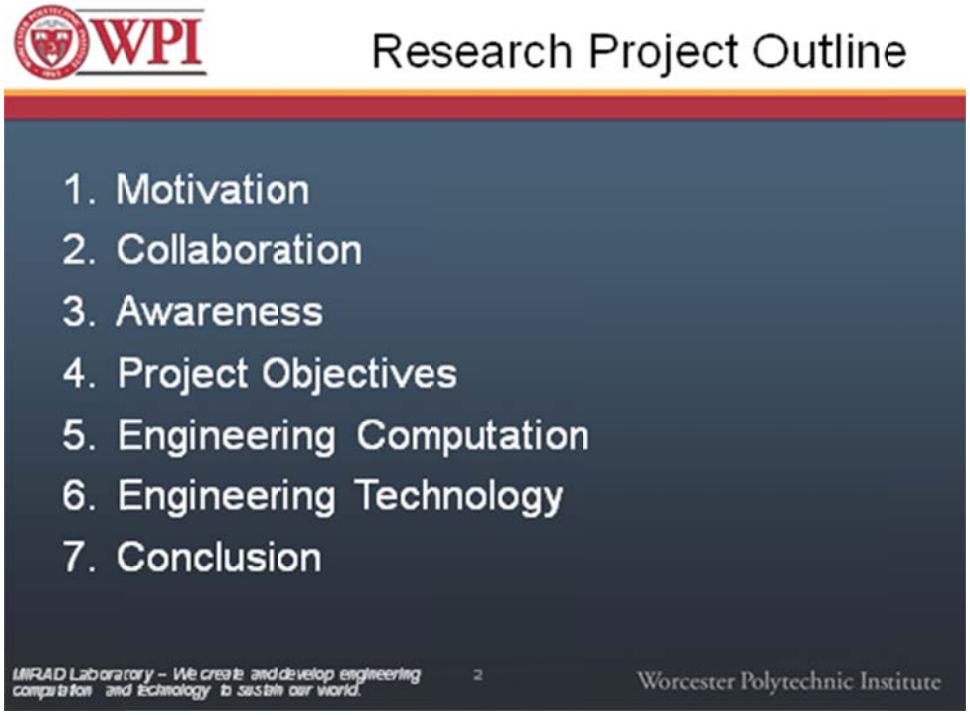


Rear View of Drainage System with Flooring

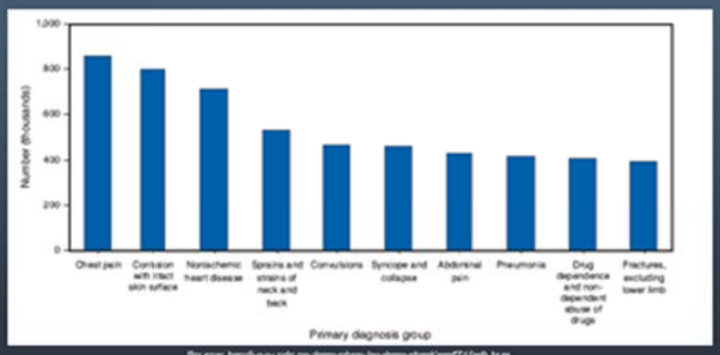


Rear View of Drainage System with Flooring Removed

Appendix I – Stryker Presentation



Motivation



Source: http://www.cdc.gov/nchs/nhds/nhdsmost10.htm

Collaboration

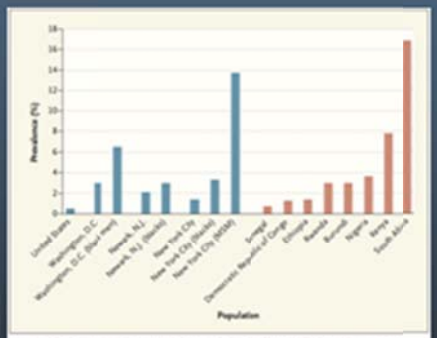
- University of Massachusetts Medical School EMS (Worcester EMS)
- Putnam-Woodstock Fire Department EMS
- Technical University of Berlin
- Tokyo Institute of Technology

Awareness

- Blood Borne Pathogens
  - Inadequate personal protective equipment.
  - Blood splashes, accidental needle pricks, and causes of fluid transfer.
  - HIV/AIDS, HBV, HCV, HDV
- Airborne Pathogens
  - Inadequate personal protective equipment.
  - TB, Influenza, VZV (Chickenpox), Meningitis, SARS

HIV/AIDS – Blood Borne Pathogen

- Estimated 1,106,400 infected in the United States
- Virulence is reduced by 90-99% outside of the body
- Mixture of bleach and water is a sufficient microbiocide

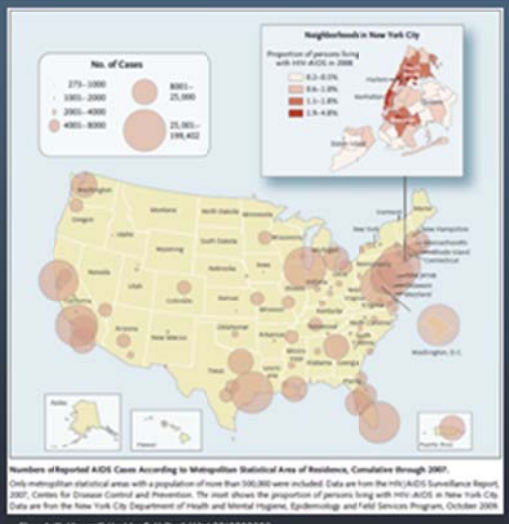


HIV Prevalence in Adults from Selected Countries in Sub-Saharan Africa and Subpopulations in the United States.

Data are from the Centers for Disease Control and Prevention, the District of Columbia Department of Health, the New Jersey Department of Health, the New York City Department of Health and Mental Hygiene, and the Joint United Nations Program on HIV/AIDS (UNAIDS). MSM denotes men who have sex with men.

El-sadr W, Mayer K, Hodder S. N Engl J Med 2010;363:1422

Reported AIDS Cases



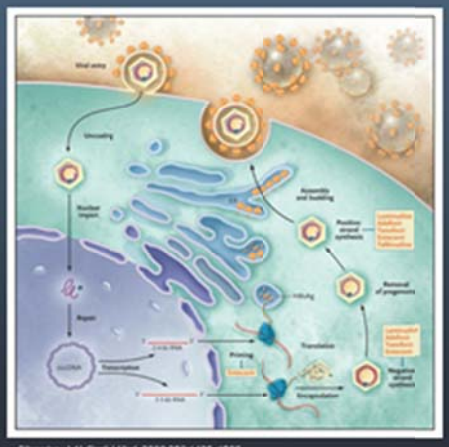
Numbers of Reported AIDS Cases According to Metropolitan Statistical Area of Residence, Cumulative through 2007.

Only metropolitan statistical areas with a population of more than 500,000 were included. Data are from the HIV/AIDS Surveillance Report, 2007, Centers for Disease Control and Prevention. The inset shows the proportion of persons living with HIV/AIDS in New York City. Data are from the New York City Department of Health and Mental Hygiene, Epidemiology and Field Services Program, October 2009.

El-sadr W, Mayer K, Hodder S. N Engl J Med. 2010;362:959

HBV – Blood Borne Pathogen

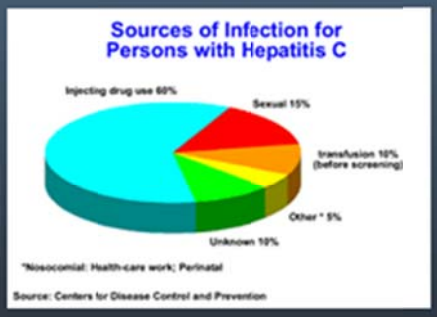
- Estimated 1.2 million carries in the United States
- Can remain virulent outside the body for at least 7 days
- Mixture of bleach and water is a sufficient microbiocide



Dienstag J. N Engl J Med. 2008;359:1486-1500

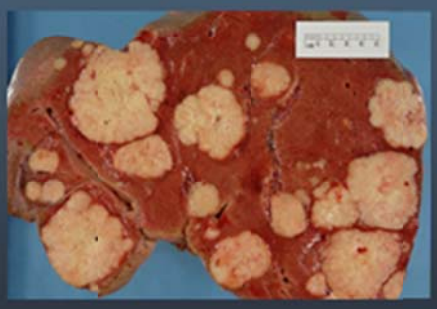
HCV – Blood Borne Pathogen

- Estimated 3.2 million in the United States
- Can remain virulent outside the body for at least 16 hours, but no more than 4 days
- Mixture of bleach and water is a sufficient microbiocide



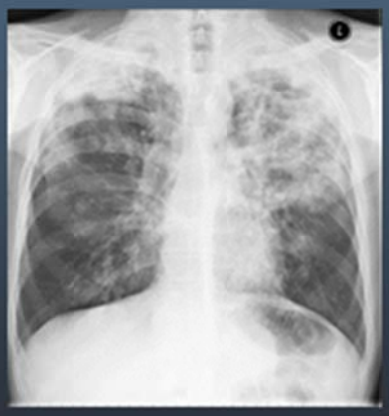
HDV – Blood Borne Pathogen

- Relatively small number of incidences
- Occurs either as a co-infection or a superinfection
- Mixture of bleach and water is a sufficient microbiocide



Tuberculosis – Airborne Pathogen

- 12,904 TB cases in the United States
  - A rate of 4.2 cases per 100,000 persons
- MDR TB on the rise
  - 440,000 cases globally
- XDR TB
  - May not be as common as MDR but serious
  - 58 countries reported having at least 1 case



MDR TB Cases from 1994-2009

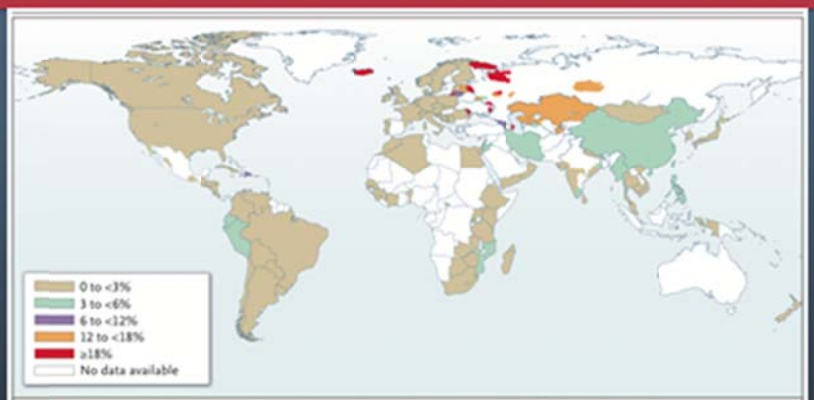


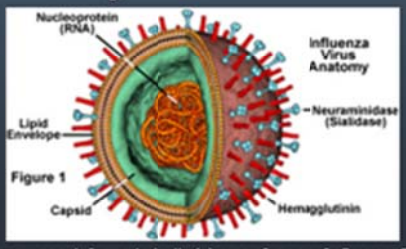
Figure 1. Distribution of the Proportion of Cases of MDR Tuberculosis among New Cases of Tuberculosis, 1994–2009.

The following 27 countries are responsible for 85% of the world's estimated cases of MDR tuberculosis and are classified as countries with a high burden of MDR tuberculosis: China, India, Russia, Pakistan, Bangladesh, South Africa, Ukraine, Indonesia, Philippines, Nigeria, Uzbekistan, Democratic Republic of Congo, Kazakhstan, Vietnam, Ethiopia, Myanmar, Tajikistan, Azerbaijan, Moldova, Kyrgyzstan, Belarus, Georgia, Bulgaria, Lithuania, Armenia, Latvia, and Estonia. Adapted from the 2010 report on MDR and XDR tuberculosis from the WHO.[1]

Nathanson E et al. N Engl J Med 2010;363:1050-1058

Influenza – Airborne Pathogen

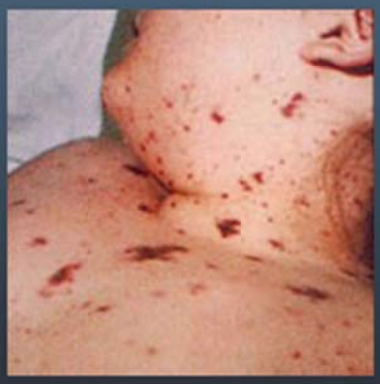
- Extensive viral surveillance in U.S.
  - 80 U.S. WHO Collaborating Laboratories
  - 70 National Respiratory and Enteric Virus Surveillance System



http://micro.magnet.fsu.edu/cells/viruses/images/influenzafigure1.jpg

Meningitis – Airborne Pathogen

- Bacterial is communicable through droplet transmission
- Approximately 1,500 cases in the US annually
- Concern for people living in close quarters



Project Objectives

- Efficient & effective pathogen detection & isolation
- Reduce ambulance downtime
- Green initiative for the pre-hospital setting

Engineering Computation

- Current ambulance cleaning procedures
- Communication
- Control & Prophylaxis

Engineering Technology

- Revise decontamination procedures and protocols
- Investigate more efficient pathogen identification technologies

Conclusion

- ***Mission of MIRAD Laboratory:***
  - ***"Locate and Interpret Adaptable New Standards of Quality Care in the Practice of Emergency Medical Services"***
- We plan to accomplish this mission through investigation of procedure reform and technological evaluation.

Questions/Comments?

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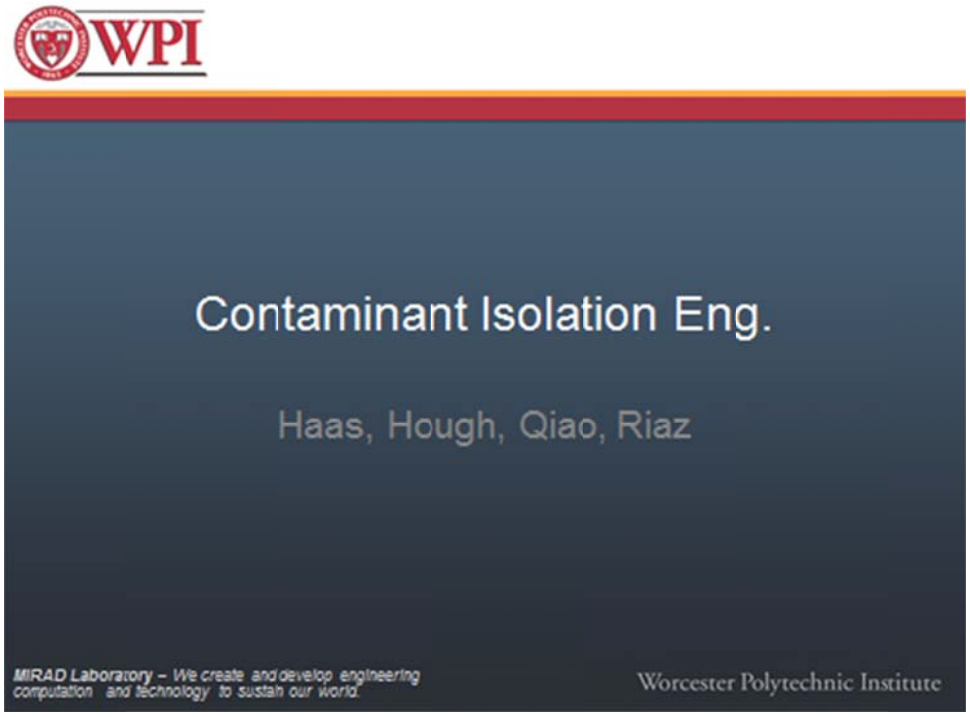
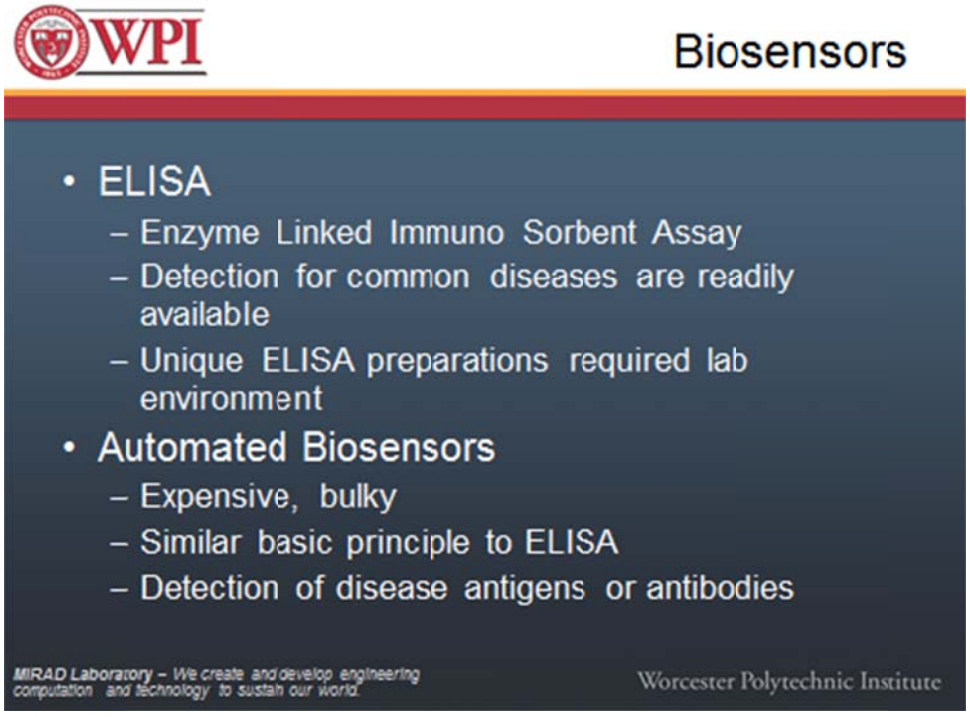
Appendix J – Project Summary Presentation



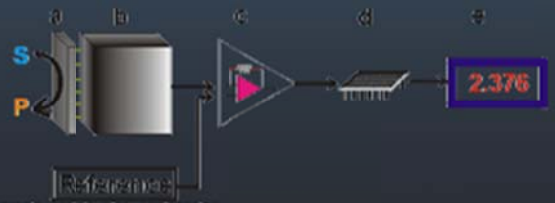


Biosensors – Requirements and Function

- Function of a pathogenic biosensor
  - Translate receptor recognition of target pathogen into detectable signals
- Requirements for pathogen sensors:
  1. High sensitivity and low detection limit
     - USDA requires zero tolerance of certain strains of bacteria
  2. Rapid analysis time
  3. Simultaneous detection and identification of different strains of bacteria
     - An array type of sensor displaying independent
  4. Portability and ease-of-use are important for on-site monitoring

Biosensors – Mechanism

- Biocatalyst: reacts with desired substance, converting substrate to product
- Transducer: emits electric signal following chemical reaction
- Amplifier: amplifies output from Transducer
- Processor: processes output from Amplifier
- Display: displays reading



Air Filtration System

- Types
  - Ionization Filters
  - HEPA Filters
- Maintain positive pressure inside room
- Keep constant *downward* airflow.
- Protect Doctors/EMTs from airborne or droplet contact transmission.

Current Ambulance Cleaning Procedures

- Personal Protective Equipment
  - Eye Protection and Gloves (typically mandatory)
  - Isolation Gown, Mask, and Booties (if necessary)
- General Procedure
  - Hold cleaning agent mixture dispenser 10 inches from surface and use quick, short strokes
- Special Case Procedure
  - Washed manually, paper towels and gloves that become bloody are to be disposed of in biohazard bags.

Direct Physical Contact

- Direct contact between an infected person and a susceptible person
- Includes touching, kissing, transmission through blood/bodily secretions
- Most common diseases
  - HBV, HCV, HIV/AIDS
  - MRSA, VRE
  - Athletes foot, Impetigo, Warts

Indirect Contact

- Contact with fomites
  - from a reservoir via inanimate objects (fomites) usually by infectious droplets
  - More difficult to avoid than direct contact
  - Organismal durability required
- Most common diseases
  - Chicken pox, common cold, influenza, hepatitis, conjunctivitis
  - Survive 24 hours to several weeks

Airborne Transmission

- Transmission that differs from Droplet Contact due to increased suspension time in air.
- Particles exist as:
  - Aerosols (fine liquid droplets)
  - Dust Particles
- May include bacterial and fungal spores.

Droplet Contact

- Transmission through *MOVING* mucous droplets
  - 1 meter from exit of mouth
    - Else it is considered as airborne transmission
- Primarily transmits respiratory diseases
- Examples of droplet contact transmission:
  - Achoo! (Being sneezed on)
  - Coughed on
  - Spat on

Source: http://www.fcs.ohio-state.edu/~sabedon/biol2050.htm

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