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Decontamination Strategy for Large Area and/or Equipment Contaminated with Chemical and Biological Agents using a High Energy Arc Lamp (HEAL)

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DECONTAMIATION STRATEGY FOR LARGE AREA AND/OR EQUIPMENT CONTAMINATED WITH CHEMICAL AND BIOLOGICAL AGENTS USING A HIGH ENERGY ARC LAMP (HEAL)

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ABSTRACT

A strategy for the decontamination of large areas and or equipment contaminated with Biological Warfare Agents (BWAs) and Chemical Warfare Agents (CWAs) was demonstrated using a High Energy Arc Lamp (HEAL) photolysis system. This strategy offers an alternative that is potentially quicker, less hazardous, generates far less waste, and is easier to deploy than those currently fielded by the Department of Defense (DoD). For example, for large frame aircraft the United States Air Force still relies on the combination of weathering (stand alone in environment), air washing (fly aircraft) and finally washing the aircraft with Hot Soapy Water (HSW) in an attempt to remove any remaining contamination. This method is laborious, time consuming (upwards of 12+ hours not including decontamination site preparation), and requires large amounts of water (e.g., 1,600+ gallons for a single large frame aircraft), and generates large amounts of hazardous waste requiring disposal. The efficacy of the HEAL system was demonstrated using diisopropyl methyl phosphonate (DIMP) a G series CWA simulant, and *Bacillus globigii* (BG) a simulant of *Bacillus anthracis.* Experiments were designed to simulate the energy flux of a field deployable lamp system that could stand-off 17 meters from a $12m^2$ target area and uniformly expose a surface at 1360 W/m^2. The HEAL system in the absence of a catalyst reduced the amount of *B. globigii* by five orders of magnitude at a starting concentration of 1.63×10^7 spores. In the case of CWA simulants, the HEAL system in the presence of the catalyst TiO_2 effectively degraded DIMP sprayed onto a 100mm diameter Petri dish in 5 minutes.

1. INTRODUCTION

1.1 DOD DECONTAMINATION OVERVIEW

The Department of Defense (DoD) considers the employment of Chemical, Biological, Radiological, Nuclear (CBRN) weapons a serious threat to military operations world-wide.[1] To combat this threat the DoD has designed and published a CBRN defense framework. One of the pillars of this framework is to be able to sustain CBRN operations in an environment contaminated from use of these weapons. In order to sustain operations one must be able to effectively decontaminate areas, facilities and equipment. The DoD published a multiservice procedural document on CBRN decontamination procedures and accompanying decontaminates available for use.[2] In it there are distinct procedures for the decontamination of buildings, equipment and finally a special section for the decontamination of aircraft.

The procedures for decontamination are typically dependent on the specific the type of surface being decontaminated. Appendix D of the DoD procedures on CBRN decontamination outlines the surface or materials to be decontaminated, the type of contaminate, and the decontamination method.[2] Most of these methods rely on the use of traditional agents such as Super Tropical Bleach (STB), 2% household bleach solution and/or foaming agents containing hydrogen peroxide. These decontaminants are highly effective at degrading and/or killings CWA and BWA. Unfortunately they are also highly corrosive and can damage the surfaces they come in contact with – to the extent that their use in the decontamination of aircraft exteriors is prohibited by U.S. Air Force tactical procedures governing the decontamination of large frame aircraft.[3]

1.2 USAF AIRCRAFT DECONTAMINATION

For aircraft decontamination, the Air Force relies on a three step process for exterior decontamination. According to standard Air Force operations the aircraft is placed in a remote area and usually allowed to weather for at least one hour. Following weathering, the aircraft is flown for at least 2 hours at an altitude of 10,000 ft; a process termed "air washing" and later washed repeatedly using HSW (800-1,600 gallons/fresh water). Studies conducted by the Air Force demonstrated that this process removed significant amounts of CWA. However, test data indicated that depending on the CWA (most notably VX), amounts capable of causing pathological conditions can still remain on the aircraft even after six washings.[4] This study called the Large Frame Aircraft Decontamination Demonstration (LFADD) demonstrated that this current strategy (which can take in excess of 12 hours) cannot clean the aircraft to acceptable levels which will allow its use by unprotected personnel and permit the aircraft to be flown without restriction.

In addition, logistical burdens are created following washing, this "wastewater" (1600+ gallons) must then be collected, decontaminated and disposed of. Additionally, once the aircraft is decontaminated, the decontamination site and all of the materials used in the process (e.g., boots, gloves) must be decontaminated as well. Typically this is accomplished by applying chlorine-based solutions and copious amounts of water.

1.3 PROPOSED STRATEGY

In this manuscript an alternative to the decontamination strategies available in current DoD procedures is theorized. This strategy relies on the use of HEAL systems for CWA and BWA decontamination of large aircraft, areas and/or other equipment. ORNL operates two HEALs that are capable of generating power densities on the order of a laser beam (20 kW/cm^2) over large areas (1,000 cm^2). The high intensity lamps were originally designed for short duration material processing at close

range, but the beam optics can be adjusted such that the illuminated area covers 12 m^2 with an incident energy intensity of 1360 W/m^2 at a standoff distance of 17 m. Like natural sunlight, the energy of the lamp covers the full visible spectrum and portions of the IR (Figure 1). However, unlike sunlight at the earth's surface, the HEAL system generates a significant portion of energy in the UV region (~10% < 400 nm), which is most effective against biological and chemical agents of interest.

Literature reviews indicate that light, specifically ultraviolet light, has been used since the 1930's as an effective means for creating a sterile environment.[5] VanOsedel et al. cite UV decontamination as being effective against microbial aerosols including infectious disease, vegetative bacteria, bacterial spores (e.g, *Bacillus anthracis* spores) and fungal spores.[6] When a photooxidation catalyst is added (i.e, TiO_2), concentrated energy similar to the HEAL system has been shown to effectively degrade organophosphate compounds including numerous CWA and their simulants.[7-11] If this strategy is to be effective, the efficacy of the HEAL to decontaminate BWA and CWA must be demonstrated. In the case of BWA, tests were performed using Baciulls subtilis var. Niger (commonly referred to as "BG"), a known simulant for *Bacillus anthracis*. Glass microscope slides were inoculated with BG and exposed to the HEAL varying the time of exposure. For CWA agents, the simulant diisopropyl methyl phosphonate (DIMP), a known simulant for G-series nerve agents was used. In CWA decontamination experiments, a small quantity of DIMP (5 mg -100 mg per plate) was loaded onto a glass Petri dish coated with TiO_2. This Petri dish was then exposed to the lamp for times upwards of 300 seconds.

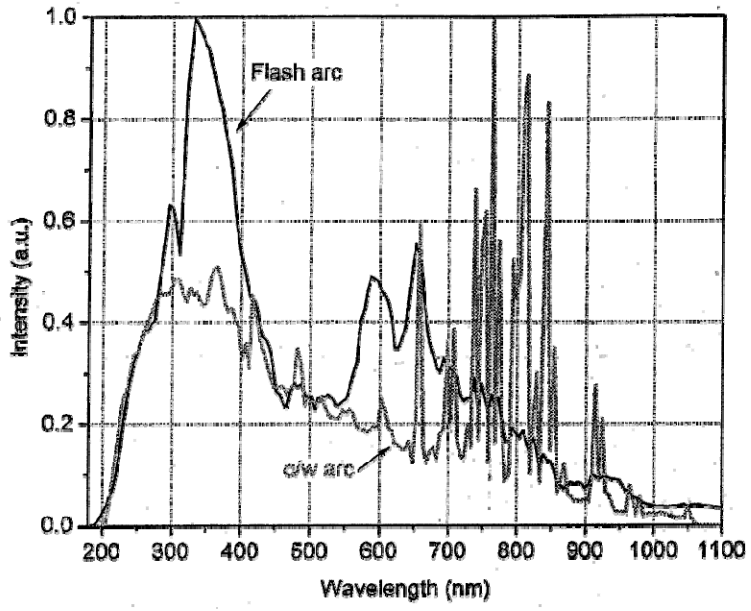


Fig.1. Emission spectrum of the HEAL system. HEAL system generates a significant portion of energy in the UV region (~10% < 400 nm), which is most effective against biological and chemical agents of interest.

2. EXPERIMENTAL

2.1 BWA SIMULANT DECONTAMINATION EXPERIMENTS

Test specimens were prepared by plating half a microscope slide with 5.42×10^6 vegetative cells and the other half of each slide with 1.63×10^7 hydrated spore cells of *Bacillus globigii*. The plates used for testing were divided into sets of three. Each set of experiments was performed by placing one plate in the processing chamber (uncovered, water cooled aluminum box), placing a second plate a short distance away on top of the process table such that it would receive only diffuse light, and by maintaining a third plate behind a physical barrier within the facility to use a control. The lamp was then started, moved over the sample, and energized for specific time periods. The lamp stand off distance and power were adjusted to simulate a large decontamination zone (12 m^2) at a standoff distance of 17m, achieving a power density of 1,360 W/m^2. Exposure times of 3, 5, and 7 s were used. The temperature and humidity data were collected prior to, during, and after testing using a RAE Systems IAQRAE (PGM5210) data logging system. The temperature was maintained at a constant 75.8°F with a relative humidity of 70%. Following irradiation each sample was cultured and the amount of growth was counted using standard microbiological technique.

2.2 CWA SIMULANTS DECONTAMINATION EXPERIMENTS

Petri dishes (100mm diameter) were prepared first with a thin layer of TiO_2 by spraying on successive coats of TiO_2 dissolved in isopropanol using an airbrush while the dish was rotated horizontally at approximately 100 rpm. A heat lamp was then used to expedite solvent evaporation between coats. TiO_2 loadings were in the range of 100 mg to 200 mg per 100 mm diameter plate. Solutions of DIMP in methanol were distributed evenly with a dropper onto the petri dish with the final challenge amount being 5 mg. Within 30 minutes of loading these petri dishes (TiO_2 + DIMP) were placed in a Teflon gas sample bag which was opened at one edge to allow insertion of the Petri dish and then released. The bag was inflated with a slight over pressure of either argon or air. Transmission spectroscopy measurements indicated the bag did not absorb light above 280 nm. The sample bag and Petri dish assembly was placed under the HEAL photolysis system at the desired distance. The HEAL standoff distance and power were regulated to produce a flux equivalent to 1,360 W/m^2. The lamp was then started and the petri dishes were moved underneath the lamp for a 300 second exposure time.

2.3 VAPOR PHASE SAMPLE ANALYSIS

Following irradiation, the atmosphere within the sample bag was withdrawn into a Triple Sorbent Trap (TST) for sorption of DIMP and its degradation products. The TSTs were thermal desorbed into a GC-MS for analysis. The system used was a HP 5890 gas chromatograph equipped with a modified injection port consisting of a coil heater through which the TST was inserted and connected to the GC injector. An HP 5972 mass selective detector was coupled to the GC for column eluent identification. Identification of spectral peaks was made via a direct comparison with spectra available with the instrument's software.

3. RESULTS AND DISCUSSION

3.1 HIGH ENERGY ARC LAMP (HEAL) SYSTEM

Oak Ridge National Laboratory's HEAL facility consists of two of the most powerful radiant energy arc lamps in the world. The systems essentially consist of a standing DC electrical arc between electrodes contained in a quartz tube filled with argon gas. The energy distributions of the lamps span a broad spectrum, from 200 nm to about 1.4 μm (see Figure 1). One of the lamps is a 300kW system equipped with a series of line focus reflectors and a capacitor bank capable of discharging 12MW in 1ms. At the designed stand-off distance of 1 cm, this results in a surface heat flux of up to 20 kW/cm^2 and temperature increase of 600,000°C/s. The second unit is a larger 750kW system outfitted with a 15 cm x 20 cm, uniform irradiance reflector. The power output of each unit can be discreetly adjusted from 1% to 100% output using a PC-based control system. These systems were originally designed for high temperature processing of structural materials and thin films, but the same technology could easily be adapted for large area decontamination efforts, as demonstrated herein.

The performance of the HEAL system is largely defined by the design of the reflector assembly that surrounds the standing DC arc. In the current configuration, the reflector assembly focuses the radiant energy to a small area on a working plane a few centimeters from the arc. Such a configuration is needed for high temperature material processing. However, a long standoff uniform irradiance reflector has also been used with this system for solar simulation testing. In this configuration, the energy from the pulsed lamp is spread out over a square meter at an energy flux of 25,000 W/m^2. Since the HEAL system uses a directed beam of light, the energy does not dissipate with the square of distance as one would expect from a point source of light. Instead, the overall energy is redistributed in the specific area defined by the reflector geometry. An appropriate reflector design could easily redistribute the aforementioned 25 kW over 12 m^2, resulting in an energy flux of ~2,000 W/m^2. Of course, the output energy can be easily controlled to approximate the 1360 W/m^2 referenced in the current research.

3.2 BWA SIMULANT DECONTAMINATION EFFICACY

The HEAL system proved to be very effective in its killing of *B. globigii* vegetative cells and spores. A summary of the efficacy experiment's in presented in Table 1. The data clearly indicates that vegetative cells are easier to kill than spores, as expected. Spore forming bacteria are considered to be one of the hardiest of BWA which is one of the main reasons it is considered such a threat. These spores are typically infectious and have extreme environmental resistance against sunlight and extreme temperatures. Even after decades of exposure, the ability of a spore to germinate and thus produce toxins (endotoxin in the case of anthrax) can remain intact.[12] Vegetative cells on the other hand are much more susceptible to the environment. For example, *Yersinia pestis* (causative agent of the plague) can remain viable in

Table 1 Percent of BWA simulant *Bacillus globigii* killed after exposure to HEAL system

	3 seconds		5 seconds		7 seconds	
	Direct	Diffuse	Direct	Diffuse	Direct	Diffuse
Vegetative	99.99997	99.4	100	99.6	100	99.4
Spore	99.99925	62.0	99.99976	63.0	99.99996	57.0

unchlorinated water and most soil for weeks but can be killed by 15 minutes of exposure to 55° C temperatures or through several hours of exposure to sunlight.[12] The HEAL system provides a quick alternative to natural weathering. As shown in Table 1, the HEAL was extremely effective even in extremely short exposure times. Even after as little as a 3-second exposure, the HEAL system was able to reduce the concentration of the spore and vegetative cells by 5 orders of magnitude.

3.3 CWA SIMULANT DECONTAMINATION EFFICACY

The photocatalyzed (TiO_2 catalyst) oxidation reaction of DIMP using the HEAL system effectively degraded DIMP at concentrations of 0.64 g/m^2. Figure 2 shows the GC-MS total ion current chromatographs from two test runs using 300 s of irradiation in argon (lower chromatograph) and air (upper chromatograph) chamber atmospheres. The experiment with an atmosphere of argon was tested for a dark (non-photochemical) reaction, and DIMP was identified from its retention time (ca. 19.5 min) and associated mass spectrum. No decomposition products were detected, with the only identified peaks 12.7 min (octane) and 3.8 min (diethyl ether) resulting from the background of the experimental apparatus.

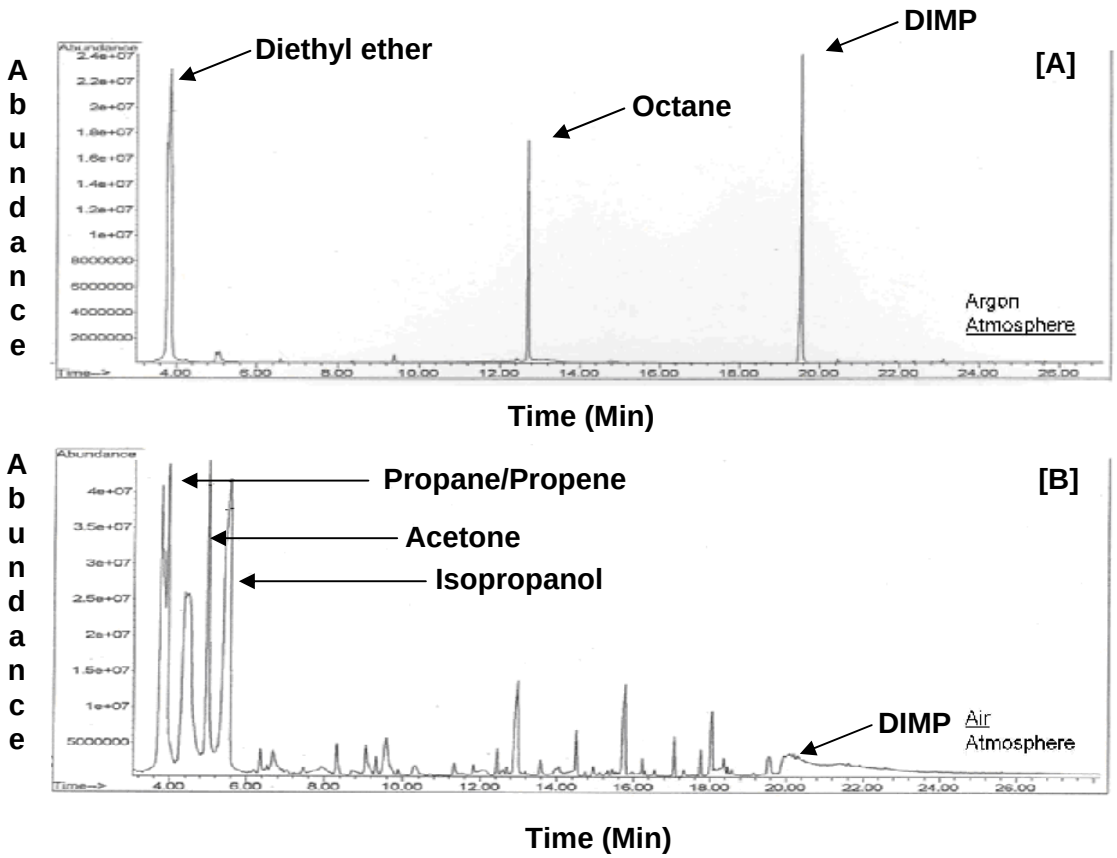


Fig. 2 Gas Chromatograph for DIMP following 300 s exposure to HEAL system. Panel A: 5 mg DIMP exposed to HEAL system + TiO_2 in argon atmosphere. Peak at 19.8 min is DIMP and background peaks Diethyl ether (3.8 min) and octane (12.7 min). Panel B: 5 mg of DIMP exposed to HEAL system + TiO_2 in air atmosphere. Residual peak of DIMP at 19.8 min is evident. Shows degradation of DIMP into propane/proprene (3.9 min), acetone (5.0 min) and isopropanol (5.6 min). These products are not evident in Panel [A].

On the other hand, the experiment with an air atmosphere demonstrated the degradation of DIMP into at least four decomposition products derived from the ispopropyl ester groups in DIMP. These products are propane and propene (ca. 3.9 min), which given the chromatographic and mass spectral conditions are not easily resolvable, acetone (ca. 5 min), and isopropanol (ca. 5.6 min). These products resulted from the further oxidation by hydroxyl radicals of the isopropyl ester groups from the DIMP. The presence of propane/propene, acetone, and isopropanol may indicate that two different chemical pathways of degradation are being utilized. In 1997 O'Shea et.al proposed two mechanisms for the hydroxyl radical mediated degradation of dimethyl methylphosphonate (DMMP).[7] In his experiments; O'Shea studied the Ti-O_2 photodegradation of a number of organophosphorous compounds including DMMP.[7]

He proposed two different reaction paths for their degradation. The first Path A involves the abstraction of a hydrogen atom from the methyl ester leading to a radical intermediate. The radical's further oxidation can lead to the formation of an acetal and finally results in the formation of methylphosphonic acid and formaldehyde.[7] Since DIMP and not DMMP is used, acetone not formaldehyde is one of the expected end-products and is clearly evident in Figure 2. The second mechanism (Path B) involves the reaction of the hydroxyl group and the phosphorous atom. This is followed by the elimination of a methoxygroup, which in the case of DMMP will eventually yield methylphosphonic acid and methanol.[7] Since DIMP is used, isopropanol is the expected product if Path B is utilized and it is also evident in Figure 2. The current experiments indicate that DIMP is being degraded via both mechanisms described by O'Shea. Our results indicate that as in the case of O'Shea et al. the hydroxyl radicals are involved in the degradation of DIMP. These hydroxyl radicals are traditionally very effective at killing BWA and degrading CWA.

While the data clearly indicates hydroxyl radicals as the main species involved in the degradation, a brief discussion of another important reaction variable (light intensity) while not directly studied in our experiments is warranted. Korman et al. and Martin et al. have shown that the rate of chloroform, $CHCl_3$, degradation in the presence of O_2 is a nonlinear function of the light intensity and the reaction is saturated in the presence of high intensity light.[13,14] The rate of reaction was dependent on the square root of intensity rather than a linear dependence. One can theorize that the reaction kinetics of a DIMP degradation may be similar to those presented by Hoffman in regards to surface bound hydroxyl radicals (TiOH·).[11] If the saturation point of the DIMP degradation can be pinpointed and correlated to the energy out-put of the lamp the effective decontamination range of the HEAL could possibly be increased (greater than 12 m^2 referenced in section 3.1) by adjusting the lamp's intensity.

3.4 HEAL DECONTAMINATION STRATEGY

The proposed strategy focuses on the ability to scale this technology so as to decontaminate as much area as possible in as little time as possible. Traditional DoD operations entail laborious procedures involving a large number of personnel. For example, a decontamination platoon typically consists of 5 different stations starting with a primary wash and ending with check to measure the amount of decontamination remaining.[2] Figure 3 is an illustration showing the typical decontamination scenario. In
this picture, station 2 is depicted in which the operator is applying decontamination foam 100 (DF-100). A typical decontamination platoon consists of 35 personnel and is required to be able to decontaminate 8 vehicles an hour. DF-100 was a decontaminant first developed by scientists at Sandia National Laboratory and its main active ingredient is hydrogen peroxide.[15,16]

Fig 3. Vehicle decontamination station. Decontamination of vehicles typically occurs in 5 separate stations. Station 2, application of decontaminant, in the case a foam such as Decontamination Foam 100 (DF-100) is being applied to a small tactical vehicle. In a typical operational scenario a decontamination platoon can be expected to decontaminate 8 vehicles an hour.

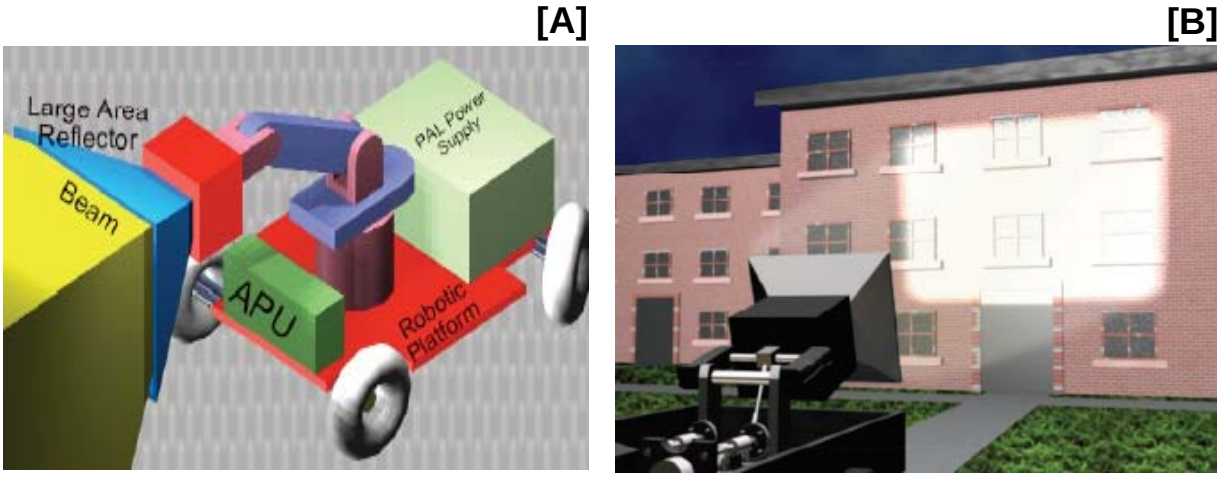


Fig 4. Heal decontamination system deployment. Panel [A]: Heal system could potentially be outfitted to mobility multipurpose vehicle (HMMWV). The system would also require an auxiliary power unit (APU) to power the vehicle. Theoretical calculations show that a lamp and reflector could be designed to diffuse light over a $12m^2$ area. Panel [B]: is a depiction illustrating how this system could be employed to decontaminate a building exterior. Current DoD procedures focus on the application of chlorine based solutions such as Super Tropic Bleach (STB) to accomplish decontamination.

The HEAL strategy has the potential to provide very rapid decontamination, potentially requiring as little as two operators, and involves processes that present less of an impact on the environment, materials, and safety concerns than traditional decontamination procedures. Furthermore, the logistical requirements involved with deploying and using a HEAL system are potentially much less burdensome than current requirements. For example, current decontamination procedures call for large amounts of water (e.g. 1,000 gallons or more, depending on the equipment) and a need for wastewater management.[2,3] The
HEAL systems logistical requirements focus primarily around electric power and the use of a TiO_2 catalyst in the case of CWA decontamination. The logistical burden could possibly be reduced further if a deployable HEAL system could be developed that is self contained and built to require a limited

number of replacement parts. A cartoon illustration depicting the HEAL in a deployment scenario is given in Figure 4. In this scenario the entire instrument can be powered by a small auxiliary power unit (APU) and mounted in the back of a military vehicle such as a mobility multipurpose vehicle (HMMWV). The potential advantages of the HEAL strategy/technology are summarized in Table 2.

Table 2 Potential benefits of HEAL decontamination system

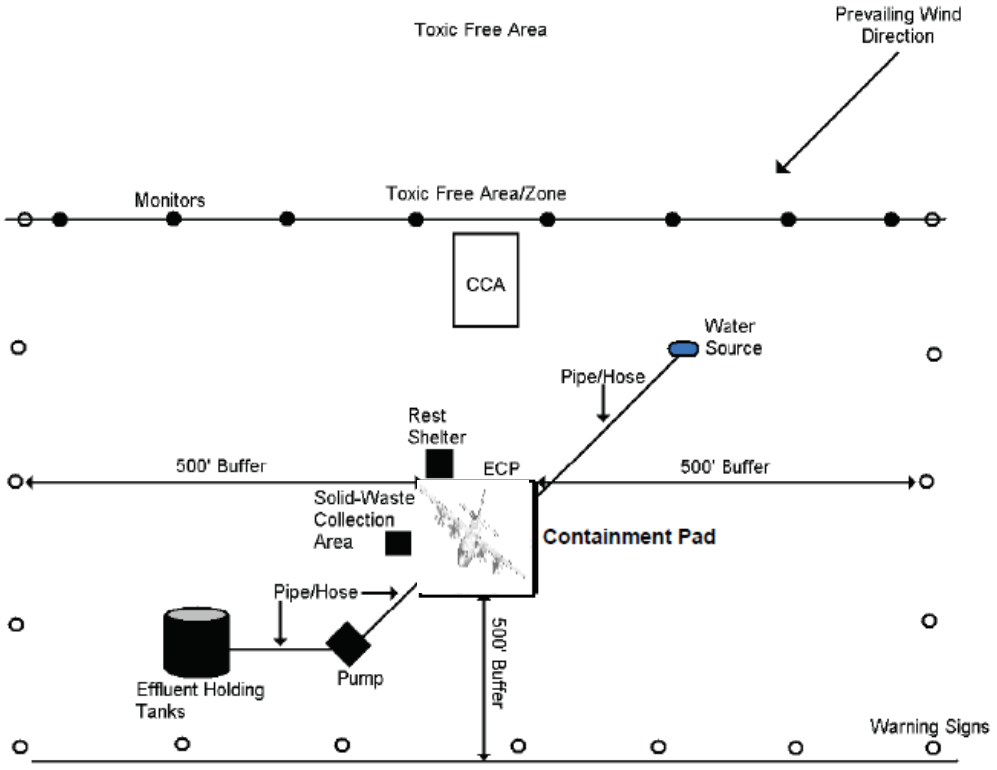
Features	Benefits
Non-traditional decontamination method. Utilizing UV spectra for BWA decontamination. Utilizing photoxidation TiO_2 catalyzed reaction for CWA decontamination	Offers non-corrosive alternative to traditional aqueous based decontamination strategies such as chlorine solutions
	Scalable to both small and wide areas including buildings/aircraft. Could cover 150,000 m^2 BWA contaminated area in single day
	Requires less man-power than traditional decontamination procedures, semi-autonomous <5 person operation instead of 25 person decontamination platoon
	Reduced logistical burden, especially in the area of fresh water requirements

3.5 AIRCRAFT DECONTAMINATION

Aircraft decontamination poses some significant challenges for the DoD. Traditional decontamination solutions such as chlorine based solutions and decontamination foams are highly corrosive.[14] A HEAL system as described above could significantly improve the ability to decontaminate an aircrafts exterior that has been contaminated with either a BWA or CWA. In this hypothetical scenario, a comparison will be made illustrating how a HEAL system could be used to decontaminate an exterior of a C-130 aircraft that has been contaminated with a BWA and/or CWA instead of existing air force procedures.

Following contamination any aircraft contaminated will be allowed to weather (stand-alone) prior to initiating any decontamination procedures. Following weathering as previously indicated an aircraft is typically flown for a period not less than two hours. After flying, the aircraft is washed with hot soapy water a number of times. The number of times is dependent on such items as level of thoroughness of decontamination required (e.g., amount of CWA/BWA remaining after washing), and operational constraints regarding the mission.

In order to wash the aircraft, an aircraft wash down decontamination site must first be prepared. Decontamination areas are established downwind of uncontaminated zones and facilities. Figure 5 is an illustration of a stationary aircraft decontamination area. First there must be sufficient amount of fresh water present not only for the washing of the aircraft but to decontaminate the decontamination site following aircraft washing. USAF procedures call for at least 1,600 gallons of fresh water to thoroughly wash a single C-130 aircraft. Second, a decontamination pad must be constructed which is at least 500 ft away from other flight line activities. The decontamination pad for a C-130 aircraft should be at least 125 ft x 160 ft covering 20,000 ft^2 [1858 m^2].[3] It is normally constructed with water proof materials to collect all of the contaminated run-off water. This wastewater must be collected and not allowed to drain into sewers and all of it should be collected and tested. Thus, as the illustration in figure 5 shows effluent storage tanks with sufficient drains should be available to store any run-off. At the end of the decontamination process, the decontamination site must be cleaned to include the decontamination pad, any solid waste collected (e.g., contaminated gloves, boots) and the wastewater must be neutralized.



the prevailing wind-direction. USAF decontamination procedures involve use of copious amounts of water. Contaminated run-off must be collected neutralized and disposed. From Ref. [3]

It is our belief that a small portable decontamination system (such as that illustrated in Figure 4) could significantly improve existing USAF aircraft decontamination procedures. The HEAL does not require large amounts of water. Eliminating or reducing the amount of water used lessens the logistical footprint by reducing the size of wastewater storage facility and/or the fresh water source required.

Soap and water methods of decontamination can be very time consuming. According to USAF procedures, it takes approximately 1-2 hours to wash an aircraft, dependent upon size, amount of contamination, and the amount of water available. Previous USAF studies determined that a large frame aircraft contaminated with CWA would require at least three washings to significantly reduce contamination. Thus, decontaminating a large frame aircraft would take at least 3 hours and as long as 12 hours. The decontamination time using a HEAL is directly proportional to surface area, and offers significant time savings for some contaminates. The surface area of the C-130 can be conservatively approximated using Figure 6 by treating the aircraft as a combination of simple, thin geometric figures. The surface areas of all components, listed in Table 3, combine to a total of about 10,000 ft^2 [950 m^2]. While minimum beam times have not yet been determined, beam times of 7 seconds for biological agents and 5 minutes for chemical agents are the current estimates for decontamination of a 12 m^2 area. Therefore, a C-130 could theoretically be decontaminated of biological agent in as little as 10 minutes, and chemical agent in a 6 hr time comparable to traditional methods. Furthermore if we extrapolate this theory to a wider area, the whole decontamination pad (estimated size of 40,000 ft^2)[2,3] could potentially be decontaminated in as little as 1 hr if the pad was contaminated with a BWA.

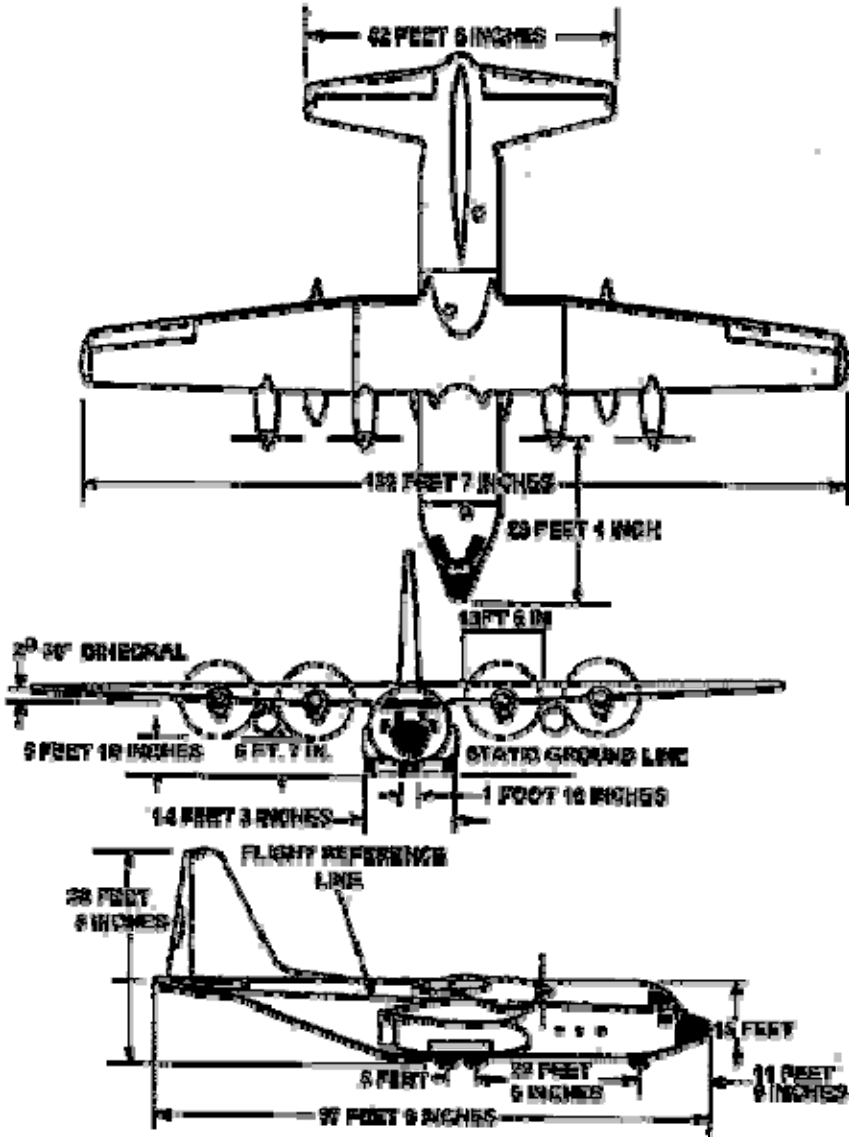


Fig 6. Dimensions of C-130H Hercules

Table 3 Approximate Surface Area of C-130H Aircraft Parts

Aircraft Part	Area [sqft]	Area [sq m]
Body	4969	462
Wing	3490	324
Horizontal Stabilizer	1375	128
Veritcal Stabilizer	345	32
Total	10179	946

4. CONCLUSIONS AND FUTURE WORK

A decontamination strategy using an HEAL system was postulated. The HEAL proved efficient in the killing of BWA simulant (spore forming bacteria) degrading the CWA simulant DIMP in the presence of a TiO_2 catalyst on simple matrices (ie, glass). The HEAL system potentially offers an alternative to traditional methods involving chlorine based solutions or formulations with hydrogen peroxide as its main ingredients. First, less water is potentially used reducing or eliminating contaminated run-off. Second, the amount of time necessary to decontaminate an area and/or equipment could be significantly curtailed. Finally, this system has the potential to be less labor intensive than currently published methods and procedures.

Even though there is an unforeseen potential benefit in the HEAL system further work needs to be accomplished before it could be fielded. The HEAL system needs to be tested against multiple surfaces including building materials, metal surfaces (painted and unpainted) and aircraft structural material (e.g, composite material, high tensile strength steel). It is not well known how exposure to the HEAL and the TiO_2 catalyst could affect the integrity of the materials to which it is applied. A direct comparison to existing Air Force procedures in a laboratory setting is warranted to ascertain if the HEAL offers a marked improvement in decontamination efficacy and speed. Lastly, any designed system should eventually be field tested in order to further demonstrate the feasibility of the HEAL system. This testing would include but not limited be to evaluation of such items as TiO_2 delivery, logistical requirements (e.g, power requirements), and ease of use.

4. REFERENCES

[1] S.A. Mccrystal, Operations in Chemical, Biological, Radiological, and Nuclear Environments, Joint Publication 3-11, August 2007, This document is available from http://www.dtic.mil/doctrine.

[2] S.H. Lillie, J.N. Mathis, J.M. Kelly, B.B. Rayburn, Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological and Nuclear Decontamination, United States Department of Defense, April 2006, This document is available from http://www.train.army.mil.

[3] C.K. Kelly, Air Mobility Command, Counter Chemical, Biological, Radiological, and Nuclear Concepts of Operations, HQ Air Mobility Command, Directorate of Air, Space, and Information Operations, June 2007.

[4] R. Haddock, W. Travis, P. Feder, Formal Test Report for the Large Frame Aircraft Decontamination (LFADD), WDTS Document No. WDTS-TR-04-073, West Desert Test Center, Dugway Proving Ground, Dugway Utah, December 2004.

[5] F.L. Gates, A Study of the Bacterial Action of Ultra Violet Light, J. Gen. Physiol. 13 (1929) 231-260.

[6] D. VanOsdell, K. Foarde, Defining the Effectiveness of UV Lamps Installed in Circulating Air Ductwork: Final Report, November 2002, This report is available from the United States Department of Comm. National Technical Service.

[7] K.E. O'Shea, S. Beightol, I. Garcia, M. Aguilar, D.V. Kalen, W.J. Cooper, J. Photochem Photobio. A 107 (1997) 221-226.

[8] A. Aguila, K.E. O'Shea, T. Tobien, K.D. Asmus, Reactions of Hydroxyl Radical with Dimethyl Methylphosphonate and Diethyl Methylphosphonate. A Fundamental Mechanistic Study, J. Phys. Chem. A 105 (2001) 7834-7839.

[9] J.A. Moss, S.H. Szczepankiewicz, E. Park, M.R. Hoffman, Adsorption and Photodegradation of Dimethyl Methylphosphonate Vapor at TiO_2 Surfaces, J. Phys. Chem. B 109 (2005) 19779-19785.

[10] M.A. Fox, M.T. Dulay, Heterogenous Photocatalysis, Chem. Rev. 93 (1993) 341-357.

[11] M.R. Hoffman, et al, Environmental Applications of Semiconductor Photocatalysis, Chem. Rev. 95 (1995) 69-96.

[12] J.B. Woods, USAMRIID's Medical Management of Biological Casualties Handbook, Ft. Dietrick, Frederick Maryland, April 2005, This document is available from http://www.usamriid.army.mil

[13] C. Kormann, D.W. Bahnemann, M.R. Hoffman, Environ. Sci. Technol. 25 (1991) 494-500.

[14] S.T. Martin, H. herrmann, W. Choi, M.R. Hoffmann, Trans. Faraday Soc. 90 (1994) 3315-3323.

[15] U.S. Environmental Protection Agency. Building Decontamination Alternatives. Washington, DC: National Homeland Security Research Center, 2005.

[16] S.S. Talmage, A.P. Watson, V. Hauschild, N.B. Munro, J. King, Current Organ. Chem. 11 (2007) 285-298.