# Air Force Institute of Technology

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# *Ultraviolet Light Emitting Diode Use in Water Disinfection*


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# Background/Scenario 1



- Deployed troops require safe drinking water
- Requirement is typically met through bottled water
  - Must be delivered to the base—usually under dangerous conditions
  - Creates an enormous amount of waste
- Current on site treatment has associated issues ranging from chemicals to large power requirements
- Investigating a new way to treat water on site easily and efficiently

# Current drinking water treatment and distribution



ROWPU

TWPS

Water bladders and distribution

Water trailer

# UV LED Irradiation



- Alternative to chemical disinfection (e.g., with chlorine)
  - Broad-spectrum antimicrobial agent
  - Minimal disinfection byproduct formation
- Disrupts DNA, RNA preventing microorganisms from reproducing
- LEDs
  - Do not contain mercury as conventional UV lamps
  - Compact/robust design make more durable
  - Can start up faster, turned on/off with greater frequency
  - Require low voltage/power, more efficient, longer lives
  - Low voltage, DC, consistent with solar power

# UV LED Disinfection



- LEDs have been tested as a UV source for effective disinfection
  - Inactivated 4 different pathogenic strains of bacteria associated with food poisoning (Hamamoto et al, 2007; Mori et al, 2007)
  - Inactivated bacillus subtilis spores (Würtele et al, 2011)
  - Inactivated E. coli in water (Chatterley and Linden, 2010)
- Technology can also be applied to oxidize chemicals and biotoxins

# Pulsed LED Configuration



- Continuous current LEDs decreased emission power by 40% after 100 h
- Pulsed LEDs give same disinfection effect with ~1/10 power
- Pulsed LEDs should extend life of lamp

# Pulsed UV Irradiation

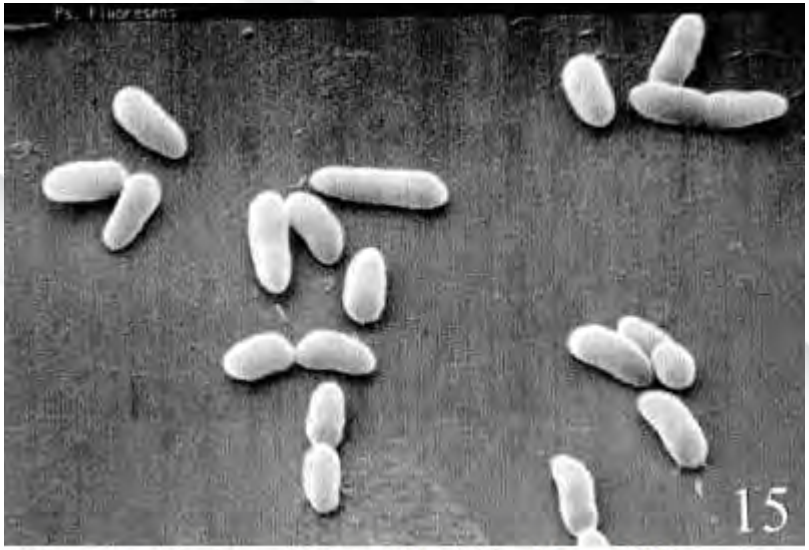


- Some research has been conducted to evaluate the disinfection capability of pulsed irradiation with an LED
  - Pulsed UVA-LED irradiation can almost completely sterilize nonpathogenic and pathogenic bacteria (Mori et al, 2007)
  - Pulsed UVA-LED irradiation was found to have a strong germicidal effect and cause the disappearance of hyphal forms of Candida (Li et al, 2010)

# Target Organism



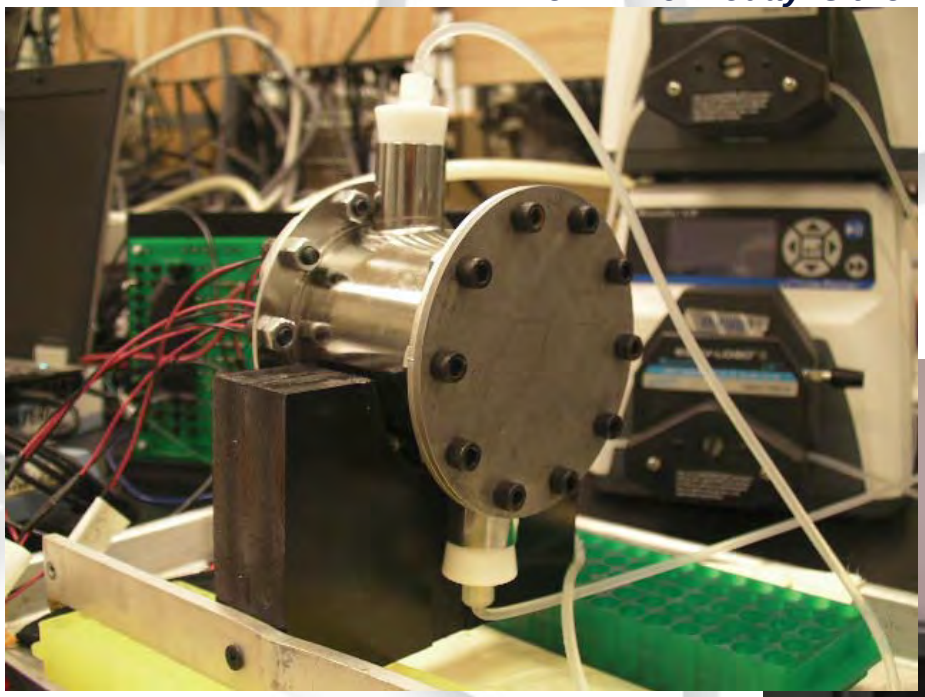
- Evaluate the effectiveness of pulsed UV LEDs to disinfect drinking water
- *Bacillus subtilis* spores are the target organism
  - Good surrogate because the spores are difficult to treat with conventional methods

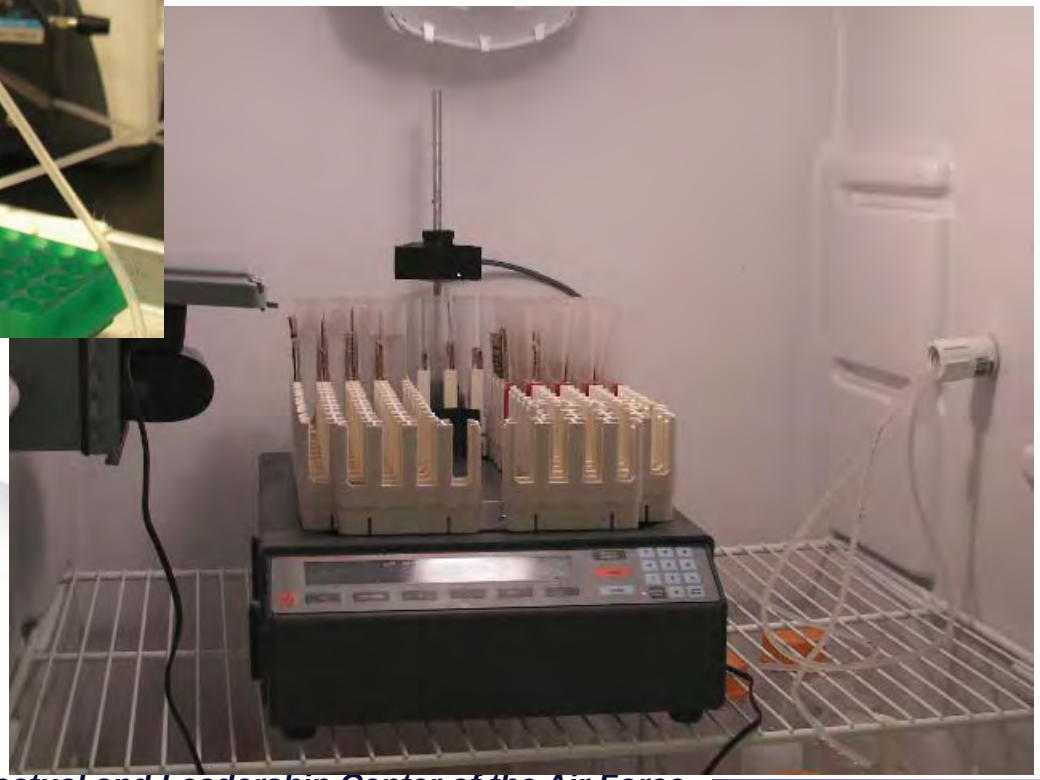



Scanning electron micrograph of Bacillus subtilis spores

# UV LED Reactor







# Background/Scenario 2



- Incident requires toxic chemicals to be decontaminated from equipment, facilities, or personnel
- Water used for decontamination might not be allowed to enter a municipal wastewater treatment facility
- EPA's Homeland Security Research Program is exploring ways to oxidize compounds in decontamination wastewater before allowing entrance to a municipal wastewater treatment facility

# AOP with UV Lamp



- An advanced oxidation process (AOP) can use ultraviolet (UV) light and hydrogen peroxide to produce hydroxyl radicals which are powerful oxidants

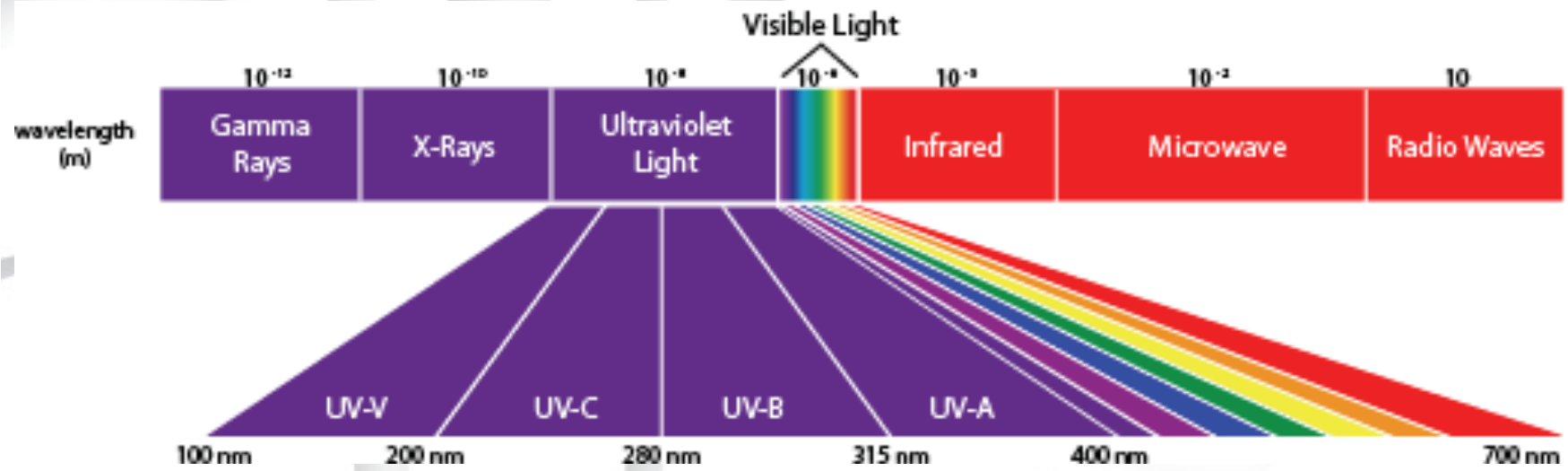
$$H_2O_2 + uv \rightarrow 2 \cdot OH$$

- Low and medium pressure mercury lamps have been used as the UV source for the AOP to remove various contaminants

# AOP with UV LED

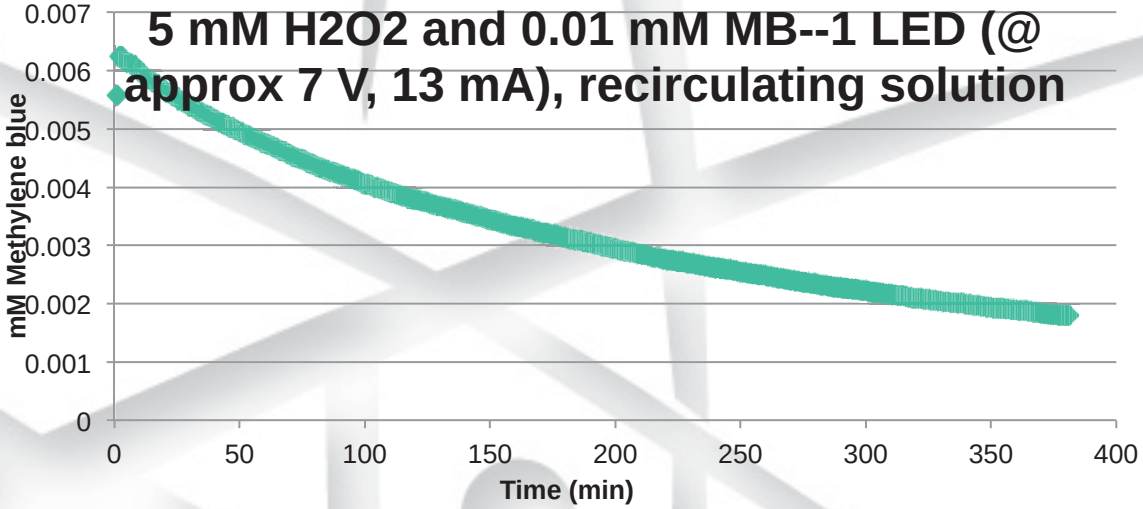


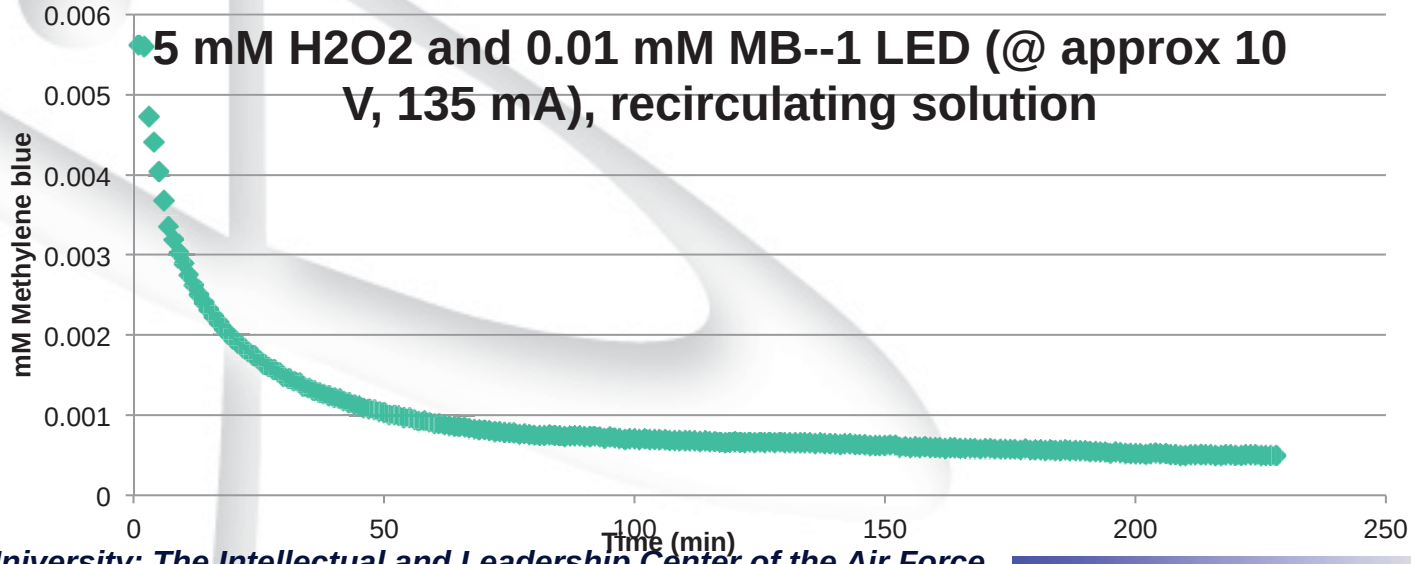
- Limited research has been conducted using light emitting diodes (LEDs) as the UV source for AOP
  - Successful degradation of phenol using UVC LEDs and hydrogen peroxide (Vilhunen et al, 2011; Vilhunen and Sillanpää, 2009)



# UV LED AOP with Methylene Blue





# Questions?

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# Backup Slides

# Research 1



- Provide a deeper understanding of the application of LEDs for AOP and their effect on the level of reactive hydrogen species produced using hydrogen peroxide
- Create a dynamic systems model which includes variables such as LED wavelength, drive current, and duty cycle
- The model will be validated through testing completed with LEDs used for AOP as well as measurements of energy output from LEDs

# Research



Project 1 is split into four parts:

1. Apparatus design—reactor chamber and LED placement
2. Establish the operational life of a pulsed LED and LED energy characterization—output as a function of current, wavelength, drive level
3. Determine effectiveness of pulsed UV LEDs for AOP with hydrogen peroxide as the reagent
4. Create a model that will be validated by parts 2 and 3 and will allow for the optimization of UV LED based AOP devices

Project 2: evaluate pulsed LEDs to disinfect water

# Research 1



- Investigate the effect of pulsed and continuous current UV LED light for AOP using hydrogen peroxide as a reagent
  - Determine if the operating mode of the UVC LED changes the effectiveness of generating hydroxyl radicals
  - If pulsed mode is more effective, determine if there is an optimum duty cycle to maximize hydroxyl radical generation
- Hypothesis: the LEDs will be more effective at producing hydroxyl radicals and last longer when operated in pulsed mode

# Research: Why?



- Traditionally use mercury lamps for water disinfection
  - Contain mercury—lamps must be disposed of as hazardous waste
  - Require a warm up period before use
- LEDs provide an alternative to mercury lamps
  - Compact in size
  - Instant on/off capability
  - Solid state, improved robustness to physical contact
  - Can be arrayed according to their purpose
  - Require low voltage and power (enables low cost control and allows DC compatibility with solar and batteries)
  - No hazardous waste issues upon end of life

# Research: Why?



- Some research has been conducted to compare LEDs under a pulsed current with a continuous current
  - No consensus has been reached as to which mode is more effective (Meneghini et al, 2012; Buso et al 2008)

- UVA LEDs have shown equal or better disinfection capability when used in a pulsed mode over continuous mode (Li et al, 2010; Mori et al, 2007; Gadelmoula et al, 2009)

# Research



- These research efforts are expected to provide an alternate water disinfection technique which will require less power, be more durable, last longer, have equal or better disinfection capability, have no end of life issues in comparison to traditional methods, and be more suitable for contingency operations

# References




Bounty, Sarah and others. "Inactivation of Adenovirus using Low-dose UV/ $H_2O_2$ Advanced Oxidation," *Water Research*, 46: 6273-6278 (2012).

Buso, Simone and others. "Performance Degradation of High-Brightness Light Emitting Diodes Under DC and Pulsed Bias," *IEEE Transactions on Device and Materials Reliability*, 8: 312-322 (June 2008). 1 January 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4437732.

Chatterley, Christie and Karl Linden. "Demonstration and Evaluation of Germicidal UV-LEDs for Point-of-use Water Disinfection," *Journal of Water and Health*, 08.3: 479-486 (2010).

Gadelmoula, Mostafa and others. "Suitability of Ultraviolet (A)-Light Emitting Diode for Air Stream Disinfection," *The Journal of Medical Investigation*, 56: 150-156 (2009). 1 January 2013 https://www.jstage.jst.go.jp/article/jmi/56/3.4/56_3.4_150/_article.

Hamamoto, A. and others. "New Water Disinfection System Using UVA Light-emitting Diodes," *Journal of Applied Microbiology*, 103: 2291-2298 (2007). 22 March 2013 http://web.ebscohost.com/ehost/pdfviewer/pdfviewer?sid=1dc993bc-20f6-4c2e-b2d5-b532334063ef%40sessionmgr104&vid=5&hid=124.

Harimurti, Sabtanti and others. "The Degradation Mechanism of Wastewater Containing MDEA using UV/ $H_2O_2$ Advanced Oxidation Process," *National Postgraduate Conference*. 1-5. IEEE, 2011. 22 March 2013 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6136283.

He, Xuexiang and others. "Efficient Removal of Microcystin-LR by UV-C/ $H_2O_2$ in Synthetic and Natural Water Samples," *Water Research*, 46: 1501-1510 (1 April 2012). 6 November 2012 http://www.sciencedirect.com/science/article/pii/S0043135411006816.

Jung, Yeon Jung and others. "Removal of Amoxicillin by UV and UV/ $H_2O_2$ Processes," *Science of the Total Environment*, 420: 160-167 (15 March 2012). 6 November 2012 http://www.sciencedirect.com/science/article/pii/S0048969711014161.

Li, J. and others. "Enhanced Germicidal Effects of Pulsed UV-LED Irradiation on Biofilms," *Journal of Applied Microbiology*, 109: 2183-2190 (December 2010). 6 November 2012 http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=55139170&site=ehost-live.

McDonald, Kenneth F. and others. "The Development of Photosensitized Pulsed and Continuous Ultraviolet Decontamination Techniques for Surfaces and Solutions," *IEEE Transactions on Plasma Science*, 28: 89-96 (February 2000). 6 November 2012 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=842871.

Meneghini, M. and others. "Reliability issues in GaN-Based Light-Emitting Diodes: Effect of dc and PWM Stress," *Microelectronics Reliability*, 52: 1621-1626 (August 2012). 6 November 2012 http://www.sciencedirect.com/science/article/pii/S002627141100477X.

Mori, Mirei and others. "Development of a New Water Sterilization Device with a 365 nm UV-LED," *Medical and Biological Engineering and Computing*, 45: 1237-1241 (2007). 5 November 2011 http://www.springerlink.com/content/668j066286443722/fulltext.pdf.

Vilhunen, Sari and others. "Efficiency of Hydroxyl Radical Formation and Phenol Decomposition Using UV Light Emitting Diodes and $H_2O_2$," *Environmental Technology*, 32: 865-872 (June 2011).

Vilhunen, Sari H. and Mika E. T. Sillanpää. "Ultraviolet Light Emitting Diodes and Hydrogen Peroxide in the Photodegradation of Aqueous Phenol," *Journal of Hazardous Materials*, 161: 1530-1534 (2009).

Wang, Ding and others. "Medium Pressure UV Combined with Chlorine Advanced Oxidation for Trichloroethylene Destruction in a Model Water," *Water Research*, 46: 4677-4686 (1 October 2012). 6 November 2012 http://www.sciencedirect.com/science/article/pii/S0043135412004034.

Würtele, M. A. and others. "Application of GaN-based Ultraviolet-C Emitting Diodes—UV LEDs—for Water Disinfection," *Water Research*, 45: 1481-1489 (January 2011). 5 November 2012 http://www.sciencedirect.com/science/article/pii/S0043135410007773.

Yuan, Fang and others. "Degradation of Selected Pharmaceuticals in Aqueous Solution with UV and UV/ $H_2O_2$," *Water Research*, 43: 1766-1774 (April 2009). 22 March 2013 http://www.sciencedirect.com/science/article/pii/S0043135409000335.

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