PAEROSOL

Universal Microaerosol for Confined Environments Disinfection

US DOE Pacific Northwest National Laboratory

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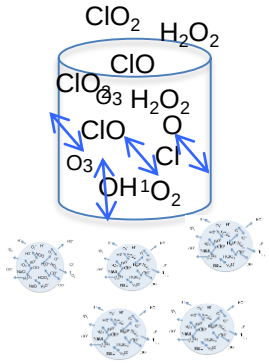
Presentation outline

Glossary:

- **NaCl** — Table Salt

- **STEL** — Electrolyzer with FEM-3 electrochemical module for production of electrochemically activated NaCl solutions

- **EAS ANOLYTE** — Electrochemically activated solution of 0.25 to 0.5 % NaCl comprising substances of manifesting oxidant qualities



- **PAEROSOL** — Semi-dry microaerosol atomized from EAS ANOLYTE **- disinfectant**

- **VAG** — Vortical Aerosol Generator for PAEROSOL production and dissemination in confined environments

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PAEROSOL Overview

- Unattended self-delivering volumetric disinfection to control HAI & CAI:

  hospitals, including distant & field healthcare settings; nursing homes, sport facilities, schools, cruse ships, aircrafts, and other confined environments

  - Concurrent disinfection/decontamination of bioagents colonized on inanimate surfaces and airborne.
  - Eradicates pathogens in entire confined environment, including otherwise inaccessible areas
  - Simple, minimal logistics & minimal manpower
  - Non toxic; no impact to sensitive equipment & interior materials
  - Compliments standard cleaning protocols
    - Can be performed before or after standard cleaning
  - User-friendly hardware requires minimal training
  - No disinfectant stocking
  - Cost and energy effective

EAS ANOLYTE Chemistry

Electrochemical activation of NaCL solution - a technology to produce meta-stable substances with very unusual physical-chemical properties

EAS ANOLYTE- product of STEL electrolysis of an aqueous solution of 0.25 - 0.5 % NaCl into a stream of environmentally compatible reactive oxidative species (ROS):

ROS: H^+, OH^- H_2O_2, $HO\cdot$, HO_2, $^1O_2$, O_2^{-}, O_3, $O^{\cdot}$, **HOCl**, ClO^-, $ClO^{\cdot}$, ClO_2

Total ROS concentration: 0.2- 0.3% or 2500 ppm

pH: 7.0 ± 0.2; ORP: +1,000±100 mV

Easy production on site

- table salt
- water - potable, non-potable, river, and other natural waters;
- STEL – electrolyzing activator

Confirmed highly bactericidal in different applications

food storage, dentistry, wound healing, etc.

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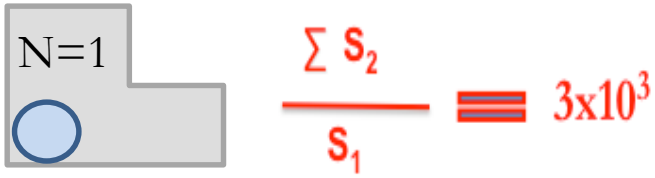
Microaerosol Fundamentals

Microaerosol

- Behaves like a gas (particles size in the range of 0.2 – 5 µm)
- Evenly fills confined environment
- Reaches all areas/surfaces including otherwise inaccessible
- High surface area to volume ratio
- Has enormous adsorption/penetration ability
- Extremely efficient in contacting complex surfaces
- Gradually desiccates
- Leaves virtually no wastes

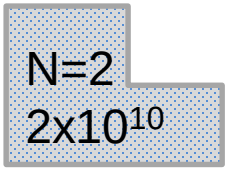
Liquid: 1 ml



S_1 = ~ 4.9 cm^2

cm^2

Microaerosol from 1 ml of liquid



S_2 = ~ 0.75 X 10^{-6} cm^2

$\sum S_2$ = ~ 1.5 X 10^4

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PAEROSOL Fundamentals

- **PAEROSOL** – semi-dry microaerosol atomized from EAS ANOLYTE
  - Eventually fills entire environment
  - Particles size in the range of 0.2 – 5 µm
  - Each droplet of PAEROSOL possesses intrinsic properties of metastable EAS anolyte
    - acts as a micro-reactor continuingly producing highly reactive mixed ROS
  - ROS are effectively offgassing from the surface of aerosol droplets through interfacial mass transfer
    - Droplets eventually desiccate
  - ROS reach/contact microorganisms residing on inanimate surfaces and airborne
    - favorable surface-to-volume ratio promotes efficient ROS offgassing
    - destroy microorganisms by disintegrating their outer membranes,
    - penetrate inside microorganisms to cause oxidative damage leading to microorganism death
  - Remains germicidal until all droplets desiccate
    - bulk gas phase ROS concentration falls below a critical level.

PAEROSOL Desiccation

O_3

O

ClO

$^1O_2$ ClO_2 ClO HClO O ClO

OH $^1O_2$ $^1O_2$

$^1O_2$ O_3 $^1O_2$

H_2O_2 H_2O_2 H_2O_2 ClO Cl

O_3 O_3 $^1O_2$

O_3- Cl $^1O_2$ OH

Cl

O_3 ClO- OH HClO

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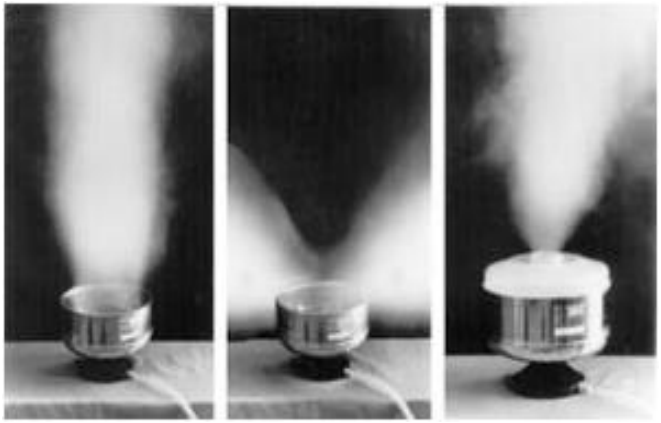
Hardware: VAG - PAEROSOL generator

- Pneumatic Vortical Generator of microaerosols (VAG)
  - Generates & diffuses PAEROSOL in confined environment
    - No extra forces for uniform distribution
  - Extra high output
    - 300-500 L of PAEROSOL/min
      - ~$5x10^9$ EAS anolyte particles per liter
  - Generates PAEROSOL at any room T˚
  - No disposable parts & electronics
  - Original vortex acoustic injectors
  - Operates by compressed air at 33-35 psi
    - In-house where available
    - Standard air compressor
      - Connected to compressed air through standard hose
    - Standard scroll pump – portable unit
  - No maintenance, no special training



Weight (Lb)		5
Dimensions (inch)	Diameter	10
	Height	11
Electronic and disposable parts		None
Material		Stainless Steel
Service life (years)		10

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Hardware: STEL Electrolyzer

- STEL - highly efficient Electrolyzers
  - 95-97% efficacy of electrolysis
  - available of different production capacity from 20L/hr. to 1,000 L/hr.
    - **Recommended dosage 1-1.5ml per cubic feet so 2L of anolyte applied to disinfect a room of 2,000-3,000 cubic feet.**

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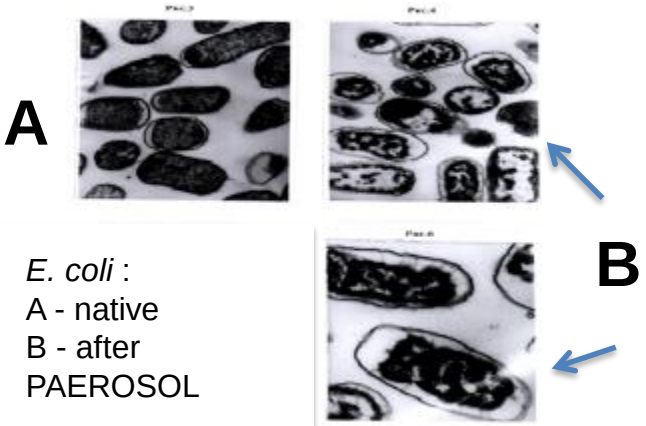
Compatibility: interior materials, electronic, and fixtures

Equipment and materials exposed to PAEROSOL	*Visual effect after consecutive PAEROSOL applications in a room of 3,000ft^3 (each application of 2-6L)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Oscillating Fan (4)	-	-	-	-	-	-	-	-	-	-
Telephone (2)	-	-	-	-	-	-	-	-	-	-
Mobile phone (2)	-	-	-	-	-	-	-	-	-	-
Computer (1)	-	-	-	-	-	-	-	-	-	-
Laptop (1)	-	-	-	-	-	-	-	-	-	-
Calculator (2)	-	-	-	-	-	-	-	-	-	-
Display (2)	-	-	-	-	-	-	-	-	-	-
DVD (2)	-	-	-	-	-	-	-	-	-	-
Lighting equipment (4)	-	-	-	-	-	-	-	-	-	-
Heaters (2)	-	-	-	-	-	-	-	-	-	-
RH/ T˚ sensor (4)	-	-	-	-	-	-	-	-	-	-
Colored PE & PP	-	-	-	-	-	-	-	-	-	-
Patterned PVC	-	-	-	-	-	-	-	-	-	-
Patterned wallpaper	-	-	-	-	-	-	-	-	-	-
Patterned cotton fabric	-	-	-	-	*Slight fading*	*Slight fading*	*Slight fading*	*Slight fading*	*Slight fading*	*Slight fading*
Patterned synthetic fabric	-	-	-	-	-	-	-	-	-	-
Lacquered wood	-	-	-	-	-	-	-	-	-	-
Bare wood	-	-	-	-	-	-	-	-	-	-
Stainless steel	-	-	-	-	-	-	-	-	-	-
Nickel-plated steel	-	-	-	-	-	-	-	-	-	-
Painted tile	-	-	-	-	-	-	-	-	-	-

Efficacy: Vegetative cells

Aerosol chamber of ~100ft^3

Test microbe	Colonized or Airborne	Organism, CFU/cm^2 CFU/M^3	Exposure to PAEROSOL, hours	Organism survived CFU/cm^2/m^3	Reduction versus natural die off, %
S. aureus	Glass, Tile, Fibrous cotton	$3x10^6$	0.5	<3	99,9999
MRSA	Glass, SS, hospital curtains	$1.5x10^6$	0.5	<3	99,9999
S. enteritidis	Green leafs, egg shell, polyethylene	$0.5x10^6$	0.5	<1	99,9999
A. baumannii	Hospital curtains, glass, SS, fibrous cotton	$2.4x10^6$	1.0	<1	99,9999
E. coli	Plastic, glass, brick, latex wood	$3x10^6$	0.5	<1	99,9999
M. tuberculosis	Tile, oilcloth both sides, cotton	$2x10^4$	4.0	<3	99,99
M. tuberculosis MDR		$1.5x10^4$	4.0	<3	99,99
S. aureus	AIRBORNE	10^6	0.2	<1	99,9999
MRSA	AIRBORNE	10^6	0.3	<1	99,9999
S. enteritidis	AIRBORNE	10^6	0.2	<1	99,9999
A. baumannii	AIRBORNE	10^6	0.5	<1	99,9999
E. coli	AIRBORNE	10^6	0.2	<1	99,9999

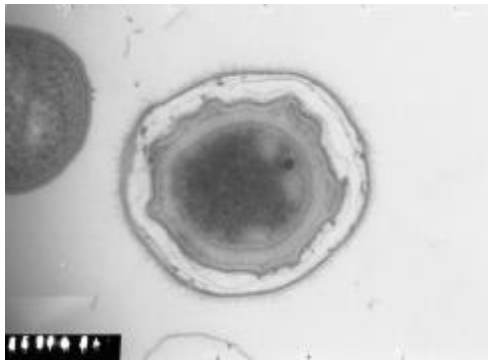


Efficacy: Microbial spores and mold

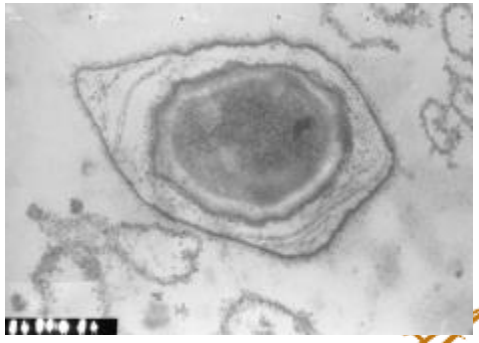
Aerosol chamber of ~100ft^3

Test culture	Colonized or Airborne	Organism, CFU/cm^2 CFU/M^3	Exposure to PAEROSOL, hours	Organism survived CFU/cm^2/m^3	Reduction versus natural die off, %
B. cereus Spores	Fibrous cotton, tile, glass	10^6	2	<1	99,9999
B.thuringiensis Spores		10^6	2	<1	99,9999
B. cereus Spores	AIRBORNE	10^6	0.3	<1	99,9999
B.thuringiensis Spores	AIRBORNE	10^6	0.3	<1	99,9999
Aspergillus niger *Penicillium* ochrochloron	Bare wood, sheetrock (mold)	~ 1x10^7	12	<10^2	99.99
	Glass (dried)	~ 1x10^7	5	<10	99,9999

B. cereus spores



B. cereus spores exposed to PAEROSOL



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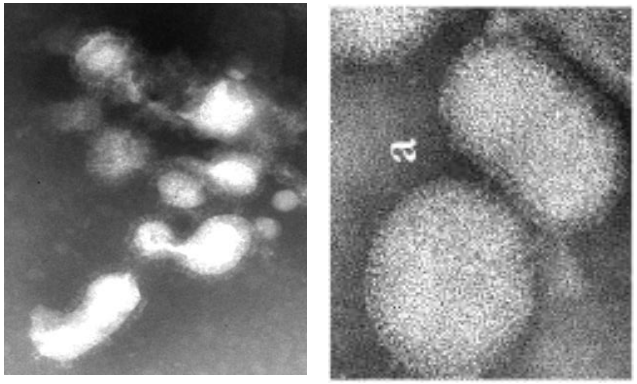
Efficacy: Viruses

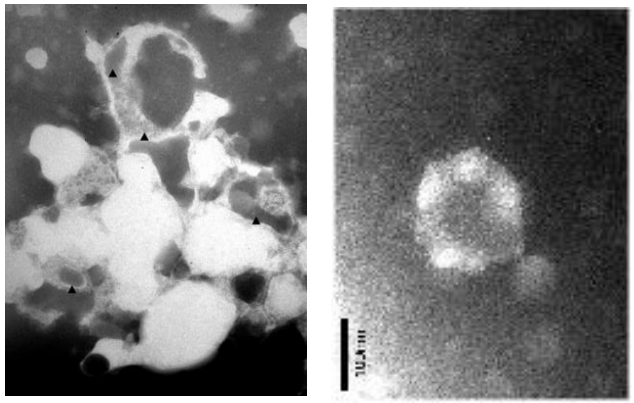
Aerosol chamber of ~100ft^3

Test culture	Colonized or Airborne	Organism, CFU/cm^2 CFU/M^3	Exposure to PAEROSOL, hours	Organism survived CFU/cm^2/m^3	Reduction versus natural die off, %
H1N1 A/Puerto Rico/8/34	Glass, fibrous cotton, tile	10^4EID$_{50}$ /cm^2	0.5	<1	99,99
H5N1a/Duck/ Kurgan/5/05		10^4EID$_{50}$ /cm^2	0.5	<1	99,99
H1N1A/ Puerto Rico/8/34	AIRBORNE	10^6EID$_{50}$/m^3	0.1	<1	99,9999
H5N1a/Duck/ Kurgan/5/05	AIRBORNE	10^6EID$_{50}$/m^3	0.1	<1	99,9999

Native virus



Exposed to PAEROSOL



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Efficacy: : Microbial spores and Mold

Room of ~3,000ft^3

Test culture	Colonized	Organism, CFU/cm^2 CFU/M^3	Exposure to PAEROSOL, hours	Organism survived CFU/cm^2/m^3	Reduction versus natural die off, %
E. coli	Plastic, glass, brick, latex wood	$3x10^6$	4.0	<1	99,9999
B. cereus Spores	Fibrous cotton, tile, glass	10^6	4.0	<1	99,9999
B.thuringiensis Spores		10^6	4.0	<1	99,9999
Aspergillus sp *Mucor sp*	Natural contamination in poultry farm	$3x10^3$	6	<5	99.9

Validation at Madigan Army Medical Center (MAMC)

Results

- 99,999% reduction on formica, tile, and curtains
- 99% - 99,99% reduction on carpet
- No negative impact to interior and electronics
- Posed no risk to those running the trial or building occupants

MAMC Pathogens tested

- *Klebsiella pneumoniae*
- *Staphylococcus aureus*
- *Pseudomonas aeruginosa*
- *B. cereus*

MAMC materials tested

- Formica
- Floor tile
- Privacy curtain fabric
- Carpet

Protocol

- 3-5x10^5/inch^2 of each organism were inoculated on each material
- Electronic devices, furniture, and fixtures remained uncovered
- Post-mortem room in the midst of crowded hospital environment
- No precautions except closing the door and shutting off air-handling system
- PAEROSOL unattended diffusion - 15 min x 2 times
  - 1.7L of EAS ANOLYTE per 2000ft^3
- Door closed for 3.5 hours to complete disinfection
- One operator – 15 min involved

Defense Threat Reduction Agency & USSTRATCOM Center for Combating WMD
www.dtra.mil

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Toxicity Study

Study set-up

- Outbred white mice: males – different age and weight
  - Multi experimental and control groups - high external validity test
    - Directly exposed to PAEROSOL for 30-60 min
- Swiss Webster pathogen-free (SPF) female mice
  - Multi experimental and control groups - high internal validity test
    - Directly exposed to PAEROSOL for 30-60 min
- All groups were observed during 14 consecutive days
  - Daily: behavior, motor activity, convulsions, irritant reactions, state of hair and skin, appetite, and changes in body weight
- On day 14, blood samples were obtained under anesthesia and animals were euthanized
  - Organs pathology, hematology, immunology, histology, and statistical analysis

Results

- **NON-TOXIC**

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PAEROSOL Distinctive Features

- Does not use or generate toxic chemicals
- Minimal decontaminant volume
  - 2L of EAS ANOLYTE per 2,500 ft^3
- Self-disappearing decontaminant
  - Does not result in pathogens resistance to disinfectants & antibiotics
- No facility prerequisites to perform disinfection
  - Highly effective in the presence of organic load (on soiled surfaces)
    - Does not require thorough pre-cleaning of inanimate surfaces
- No requirements for strict isolation of disinfecting facility
  - Can be routinely applied in vacated rooms in the midst of crowded buildings, like hospitals
- Time-practical - from minutes to hours
- Easily deployable for consequence management, including in distant settings

Capability

- Prevent cross contamination of occupants in confined environments by routine short - term (10-15 minutes) regular application
  - eradicate airborne pathogens associated with droplet nuclei or dust particles containing infectious agents that may remain suspended in the air for long periods of time
    - Minimize number of live pathogens eventually settled on inanimate surfaces
    - Reduce risk of infection transmission beyond contaminated environment
- Eradicate infective organisms on inanimate surfaces and airborne by thorough disinfection requiring 3-4 hours.
  - Reduce manpower and improve a quality of laborious final cleaning protocol
    - Minimize risk of cross contamination and infection transmission beyond contaminated environment
- Prevent and Combat epidemics by combination of short-term and thorough applications
- Combat bio-threat agents and return facility to operation

Application

- Health Care
  - Hospitals
  - Nursing homes
  - Ambulance
- Pharmacy and medical supply production
- Food processing and food packaging
- Transportation
- Correction facilities
- Public Buildings
  - Schools
  - Gyms
  - Community & Conventional Centers
  - Airports
- Bio-threat reduction and facilities restoration

Technology Readiness Level (TRL)

- **TRL 5+**
  - PAEROSOL components were validated in relevant environment.
    - The basic technological components were integrated with reasonably realistic supporting elements so that the technology was tested in a simulated environment of 3,000ft^3
    - Includes “high fidelity” laboratory integration of components
      - Electrolyzer FEM-3 electrochemical module
        - Production cost starting from $800/device (15L EAS/hr)
          - EAS usage – 2L/ room of 3,000ft^3
      - VAG PAEROSOL generator
        - Simple engineering design with original nozzles
        - No electronics, no disposable parts, and no maintenance
      - Compressed air
        - In-house where is available
        - Air compressor, or
        - Tank with compressed air

Unattended PAEROSOL vs. Conventional Cleaning

HAZARDS INFORMATION
Virkon
Potential Health Effects
Danger: Powder is corrosive.
Causes skin burns &
irreversible eye damage.
Harmful if swallowed, absorbed
through skin or inhaled.
Do not get into eyes, on
skin, or on clothing.

HAZARDS INFORMATION
Chlorine dioxide
DANGER: Corrosive to steel, stainless steel,
and many other materials
TARGET ORGANS: Eyes, skin, respiratory
tract and mucous membrane
Harmful if swallowed.

HAZARDS INFORMATION
Hydrogen Peroxide 30%
Health rating; 3 – Severe (life)
Reactivity rating: 3 –Sever (Oxidizer)
Contact rating: 4 – Extreme (Corrosive)

HAZARDS INFORMATION
Clorox
DANGER: CORROSIVE. May
cause severe irritation
or damage to eyes and skin.
Vapor or mist may irritate.
Harmful if swallowed.
Keep out of reach of children.
Ingredient Concentration Exposure
Limit Sodium hypochlorite 6.15%

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