# Sterilization of Infected Wounds with Non-thermal Plasma

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Akron General Medical Center

Consortium for Wound Healing Research and Education

# Conflict of Interest

Sterionics, Inc. has donated the use of their non-thermal plasma device

No payment or funds have been received from Sterionics, Inc.

# Collaboration

Akron General Medical Center

Kent State University

Petrozavodsk State University, Russia

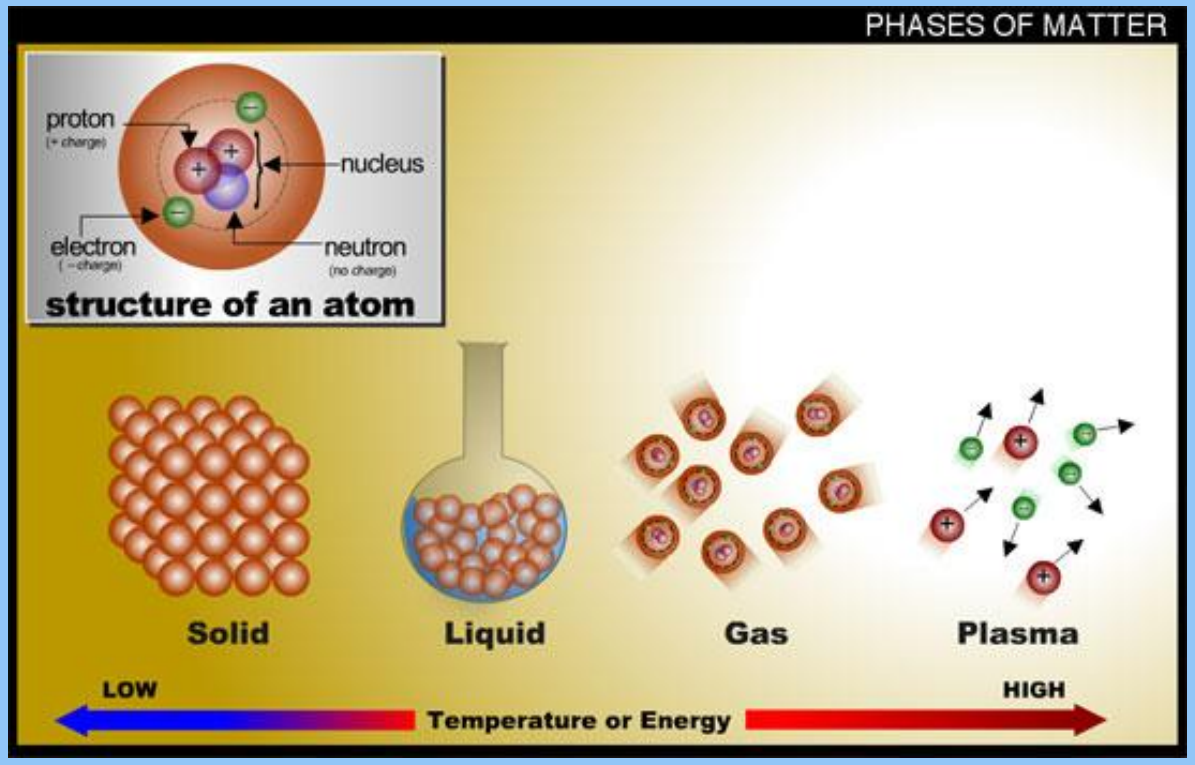
# What if ….

- Disinfect wounds without antibiotics?
- No harming tissue or causing pain?
- No resistant strains, spores or biofilms?
- Enhance healing at the same time?

# COLD PLASMA

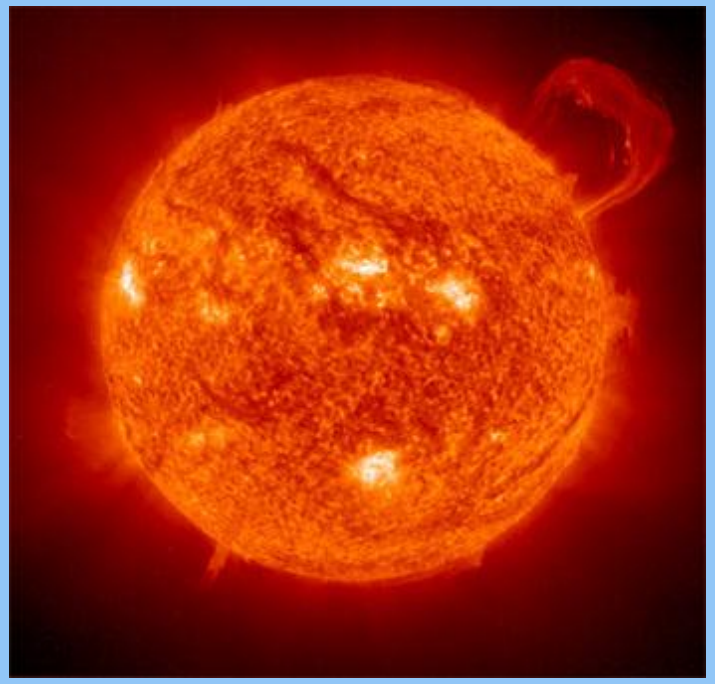
# What is a Plasma?

## 4th State of Matter




www.nasa.gov/mission_pages/themis/auroras/sun_earth_connect_prt.htm

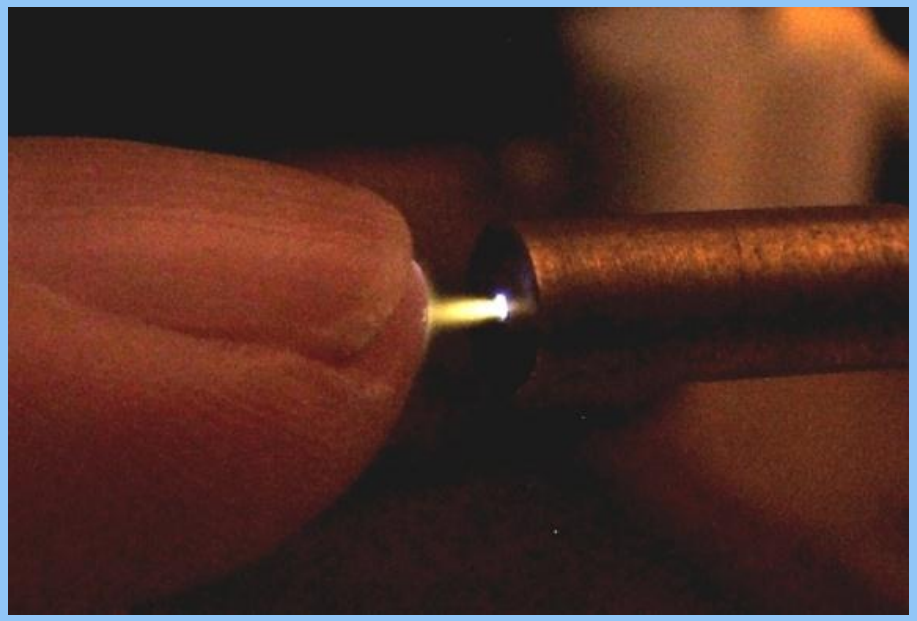
# Plasmas in Nature



# Man-Made Plasmas


# Non-Thermal Plasmas

- Active gaseous medium – contains ions, free radicals, excited atoms & molecules, UV radiation
- Cold Plasma – used safely at room temperature & atmospheric pressure



www.pulsedpower.eu/plasma_medicine.html

# How are Plasmas Generated?

Strip electrons

**Energy Source** + **Gas** ----> **Plasma**

| Energy Source | Gas | Plasma |
| --- | --- | --- |
| Extreme heat | Air | Mixture – |
| Laser light | Nitrogen | Electrons |
| Electrical current | Oxygen | Positive ions |
| Microwaves | Noble gases | |
| Radio frequency | Water vapor | |

# Nonthermal Plasma Devices

**New Journal of Physics**

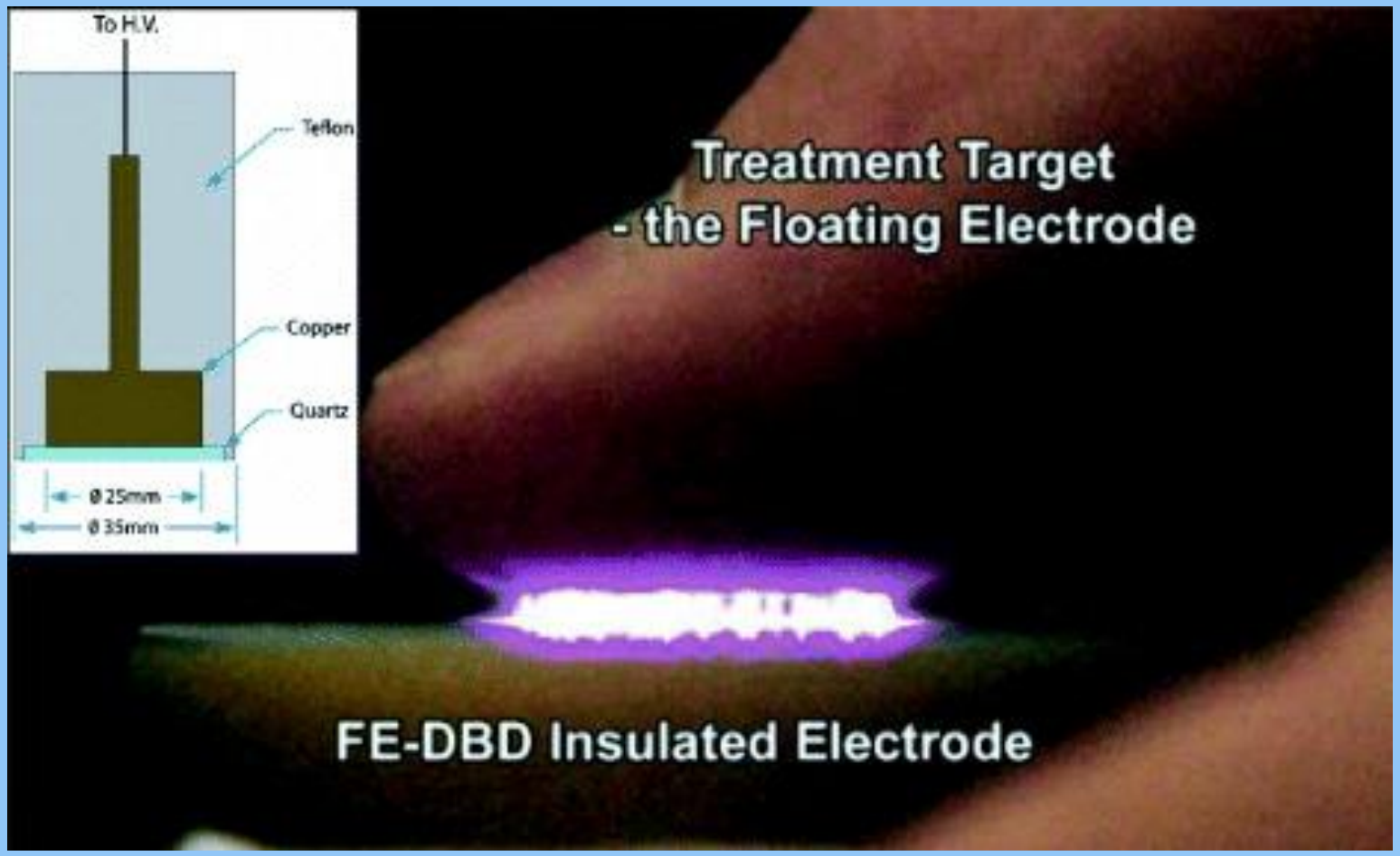
New J. Phys. **11** (2009) 115012
doi:10.1088/1367-2630/11/11/115012

## Plasma medicine: an introductory review

M G Kong[1], G Kroesen[2], G Morfill[3,5], T Nosenko[3,4], T Shimizu[3], J van Dijk[2] and J L Zimmermann[3,4]

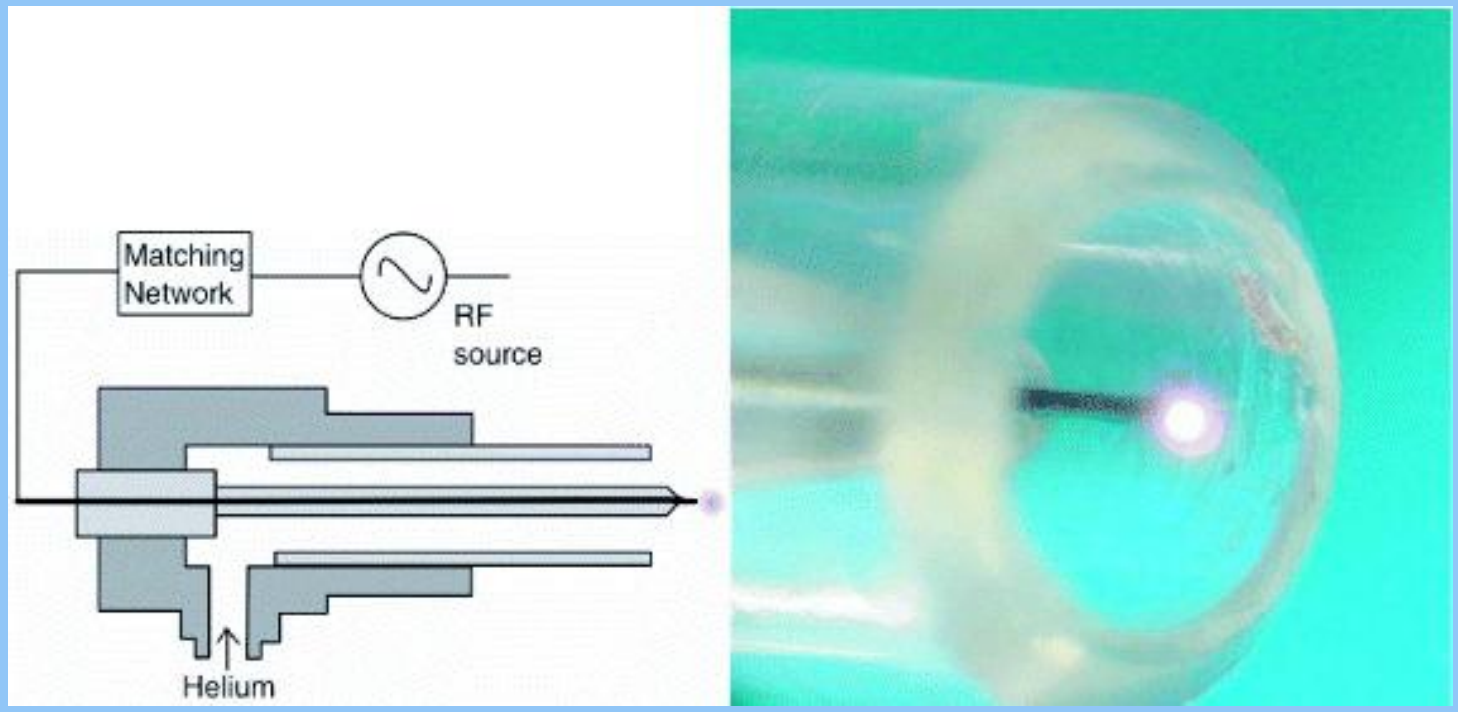
[1] Loughborough University, Loughborough LE11 3TU, UK
[2] Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands
[3] Max Planck Institut für extraterrestrische Physik, D-85748 Garching, Germany
[4] Institut für Allgemeine Pathologie und Pathologische Anatomie, Technische Universtität München,
D-81675 Munich, Germany

# Dielectric Barrier Discharge (DBD)



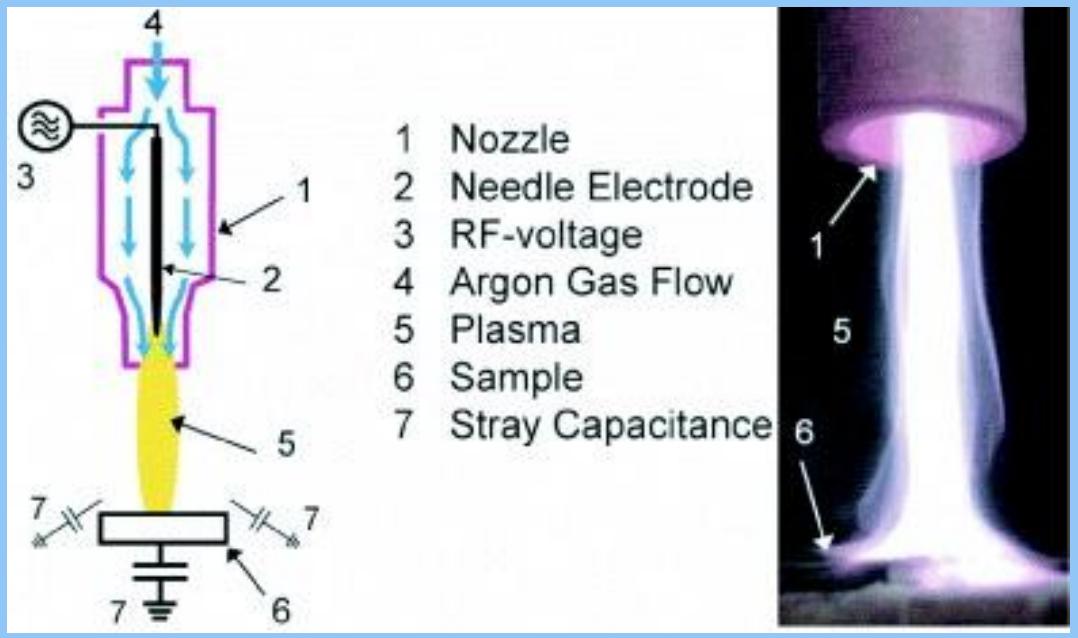

Gary Friedman & Alex Fridman, Drexel University, Philadelphia, PA

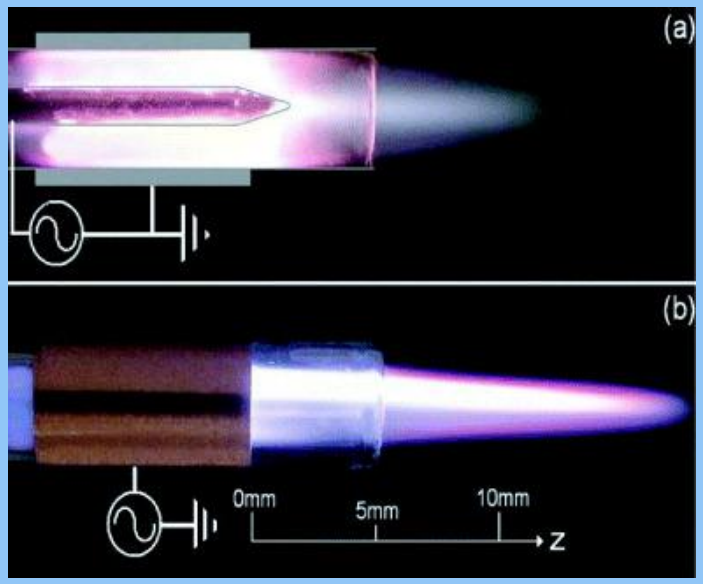
# Plasma Needle




Eva Stoffels, Eindhoven University of Technology, Netherlands

# Plasma Jets




Mounir Laroussi,
Old Dominion University, Norfolk, VA

# Pulsed Spark-based Plasma


Valery Gostev,
Petrozavodsk State University, Russia

# Biomedical Significance

- Sterilization equipment & implants
- Post-op application
- Battlefield wounds
- Oral surgery
- Disinfection of infected wounds
- Drug delivery system
- Blood coagulation

# Plasma Medicine

**Submission deadline: November 15th, 2009**

## Inaugural issue

**Submission instructions**: login to dl.begellhouse.com (or create a new account) then select "Plasma Medicine" journal when submitting the manuscript.

**Deadline**: original manuscripts must be submitted for peer review no later than **November 15th, 2009** for full consideration. Articles submitted past the deadline will appear in later issues.

**Editors-in-Chief**: Alexander Fridman, Gary Friedman, Axel Kramer, Klaus-Dieter Weltmann

**Journal Coordinator**: Holly Burnside (hollyb@coe.drexel.edu)

**Editorial Board**: Farzaneh Arefi-Khonsari, Avi D. Brooks, Sylvain Coulombe, Pietro Favia, Gregory Fridman, Gregory Friedman, Valery Godyak, David Graves, Satoshi Hamaguchi, Richard Hamilton, Mounir Laroussi, J.K. Lee, Michel Moisan, Gregor Morfill, Jean Michel Pouvesle, Richard Sawaya, Victor Vasilets, Michael Weltmann, Thomas von Woedtke

**Aims and Scope**: Technology has always played an important role in medicine and there are many journals devoted to medical applications of ionizing radiation, lasers, ultrasound, magnetic resonance and others. Plasma technology is a relative newcomer to the field of medicine. Experimental work conducted at several major universities, research centers and companies around the world over the recent decade demonstrates that plasma can be used in a variety of medical applications. Plasma is already widely used in surgeries and endoscopic procedures. It has been shown to control properties of cellular and tissue matrices, including biocompatibility of various substrates. Non-thermal plasma has been demonstrated to deactivate dangerous pathogens and to stop bleeding without damaging healthy tissue. It can be used to promote wound healing and to treat cancer. Understanding of various mechanisms by which plasma can interact with living systems, including effects of reactive oxygen species, reactive nitrogen species and charges, has begun to emerge. The aim of the Plasma Medicine journal will be to provide a forum where the above and other related topics can be presented and discussed. Existing journals on plasma science and technology are aimed for audiences with primarily engineering and science background. The Plasma Medicine, on the other hand, will bridge the gap between the plasma science, medicine and biology communities.

www.plasmamed.org for information; www.begellhouse.com and dl.begellhouse.com for submissions; greg.fridman@drexel.edu with questions

Plasma Medicine

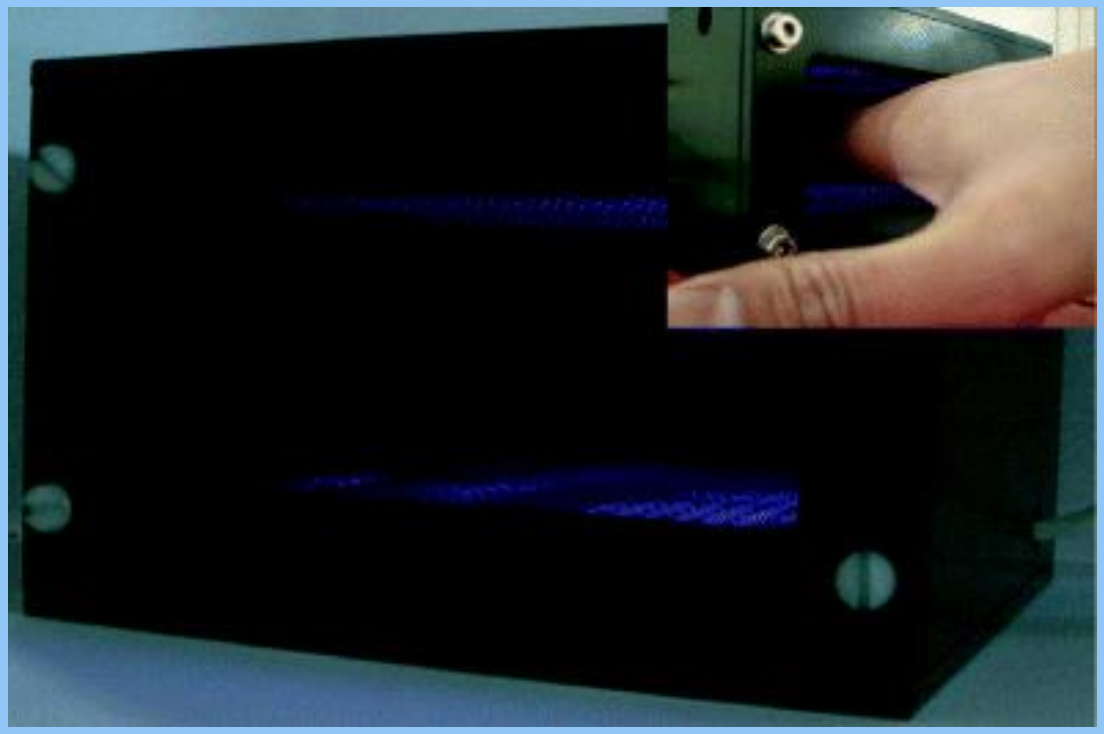
Volume 1
Issue 1

Editors-in-Chief
A. Fridman, G. Friedman, K.D. Weltmann, A. Kramer

Vol 1 2011

www.plasmamed.org

# Hand sanitizer



Gregor Morfill, Max-Planck Institute, Germany

www.physicsworld.com/cws/article/news/41072

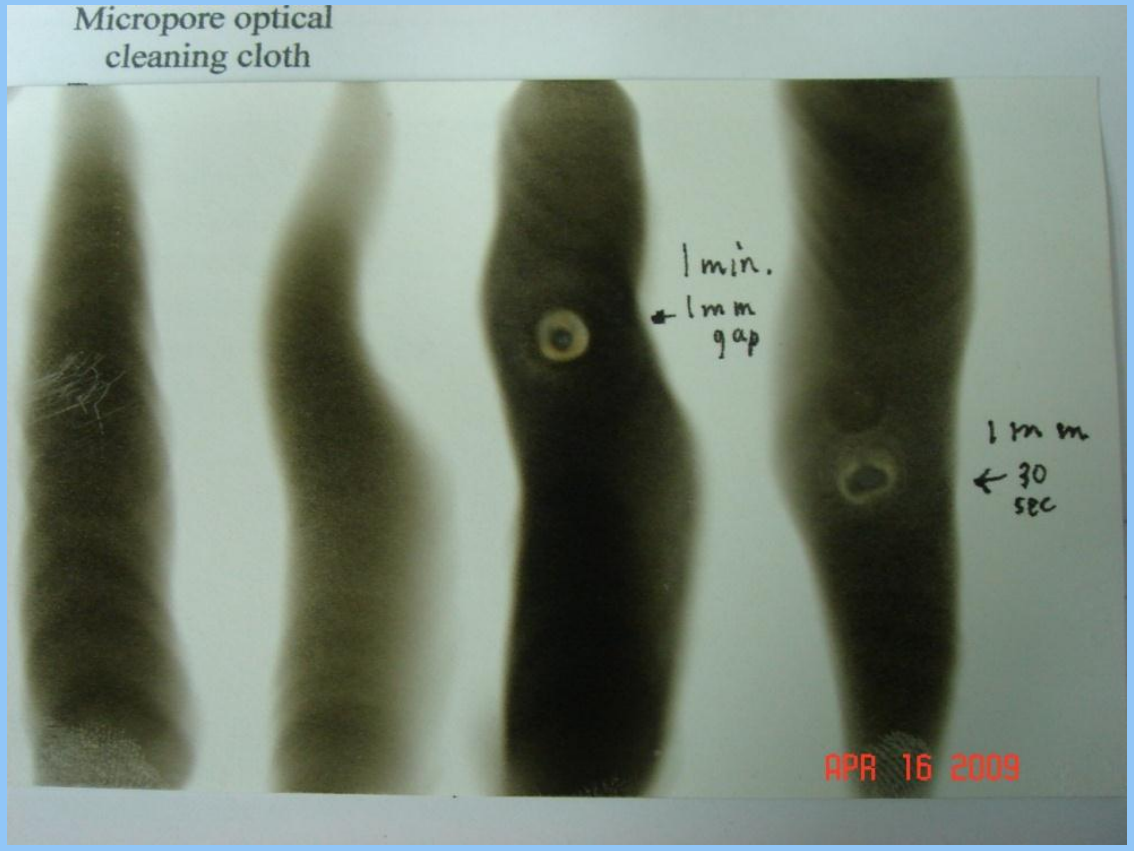
# Mechanism of Action

- UV Radiation
- Reactive oxygen species
- Reactive nitrogen species
- Composition varies – dependent on plasma generating method & starting medium

# Pulsed Spark-based Plasma

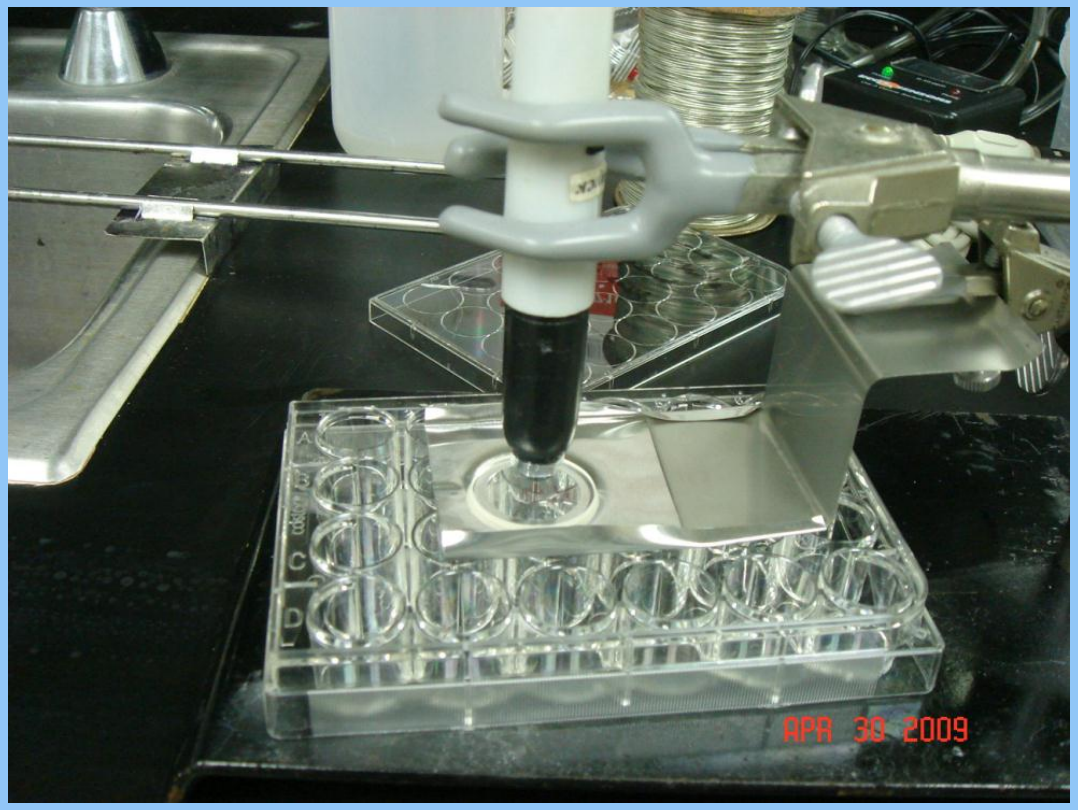
# Plume Characterization

# Soot Patterns



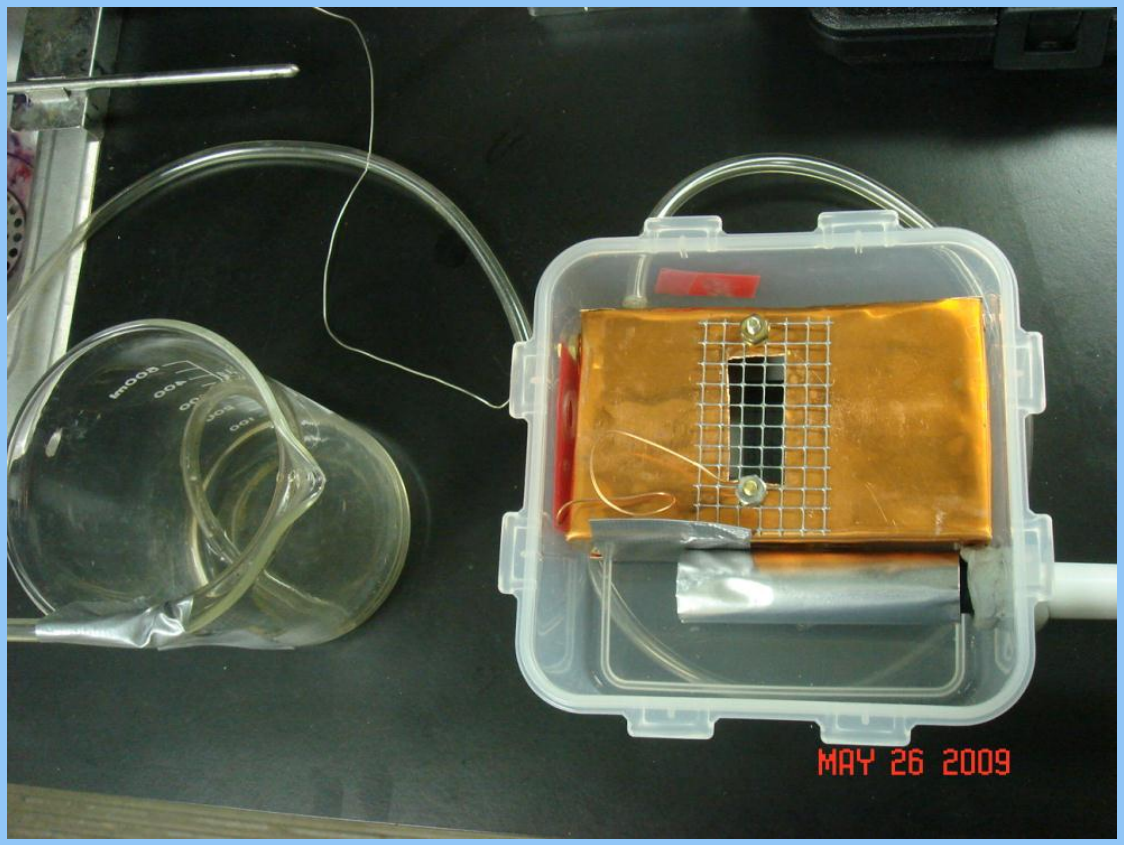

Evidence of Atomic oxygen (singlet oxygen)

# Window Transmission




Ultraviolet radiation in the UVC wavelength range

# Nitric Oxide Measurement




Nitric oxide concentration 220 ppm

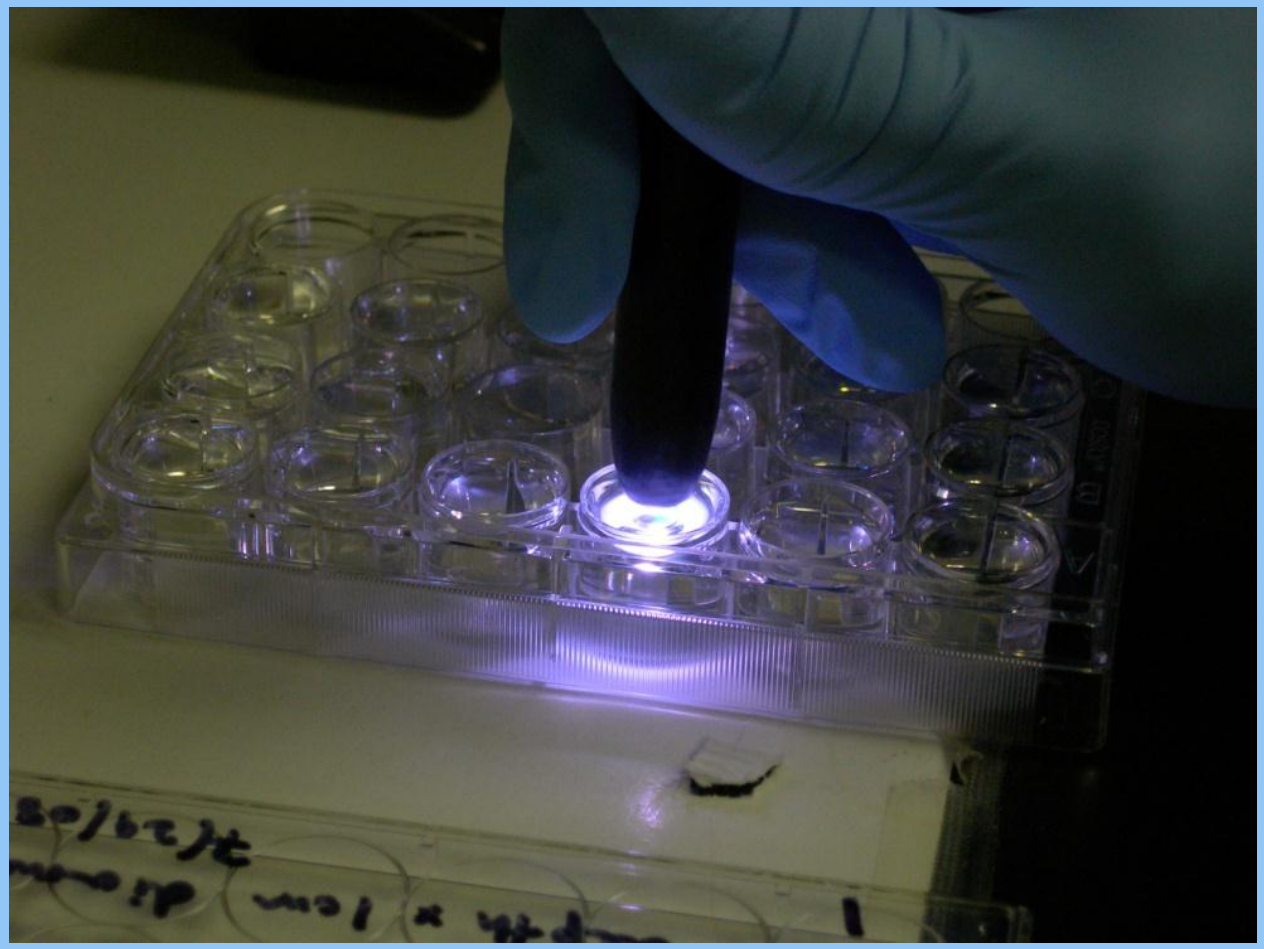
# Results Summary

- Ions and/or electrons – no net charge
- Visible light radiation ✔ - not bactericidal
- Ultraviolet radiation ✔ - bactericidal
- X-ray radiation x
- Atomic oxygen ✔
- Ozone ✔ 0.05 ppm
- Nitric oxide ✔ 220 ppm

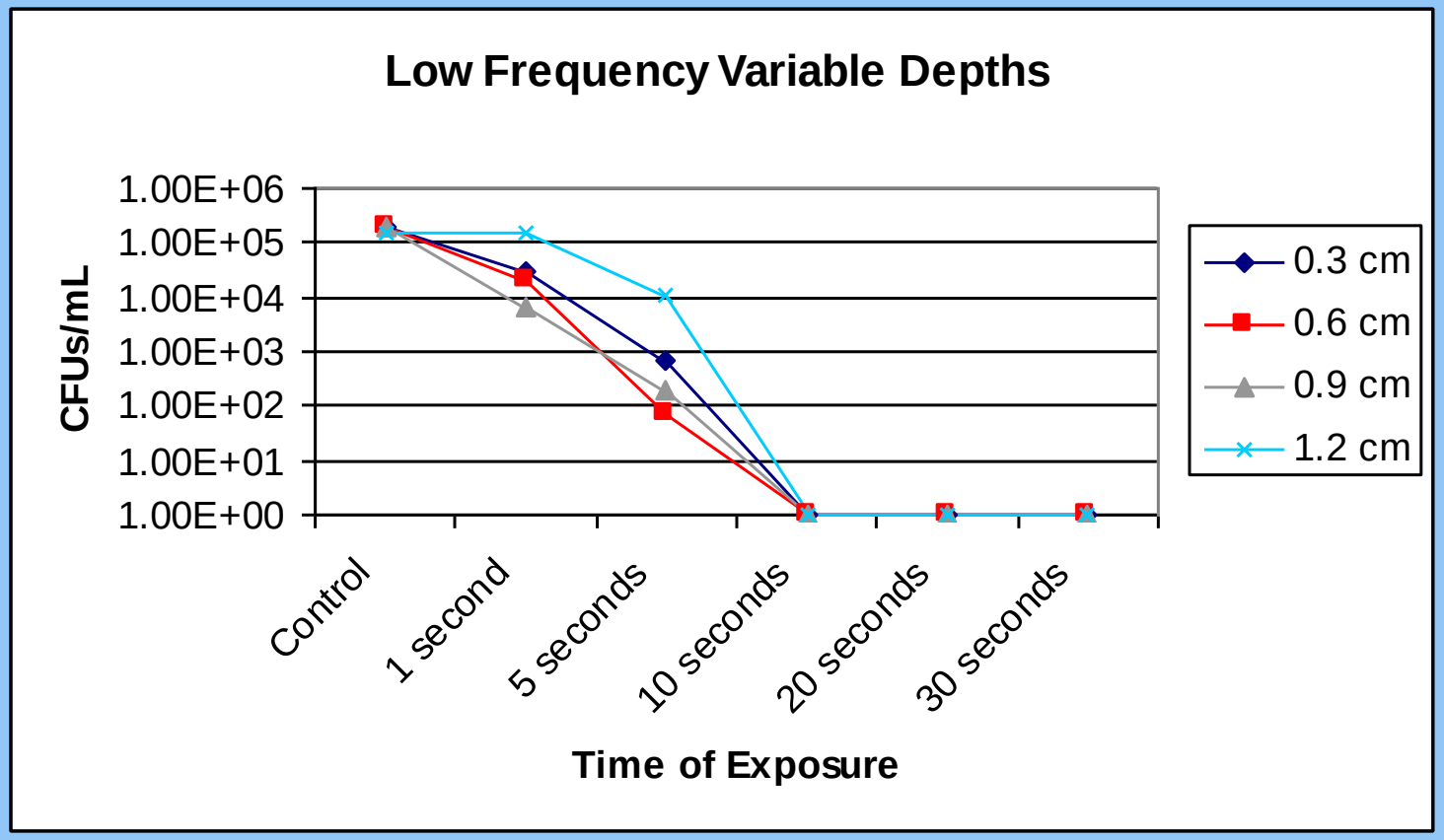
Results generated by Bruce Banks (NASA, retired) with assistance from AGMC.

# Bactericidal Experiments

# Treatment of Bacterial Suspensions

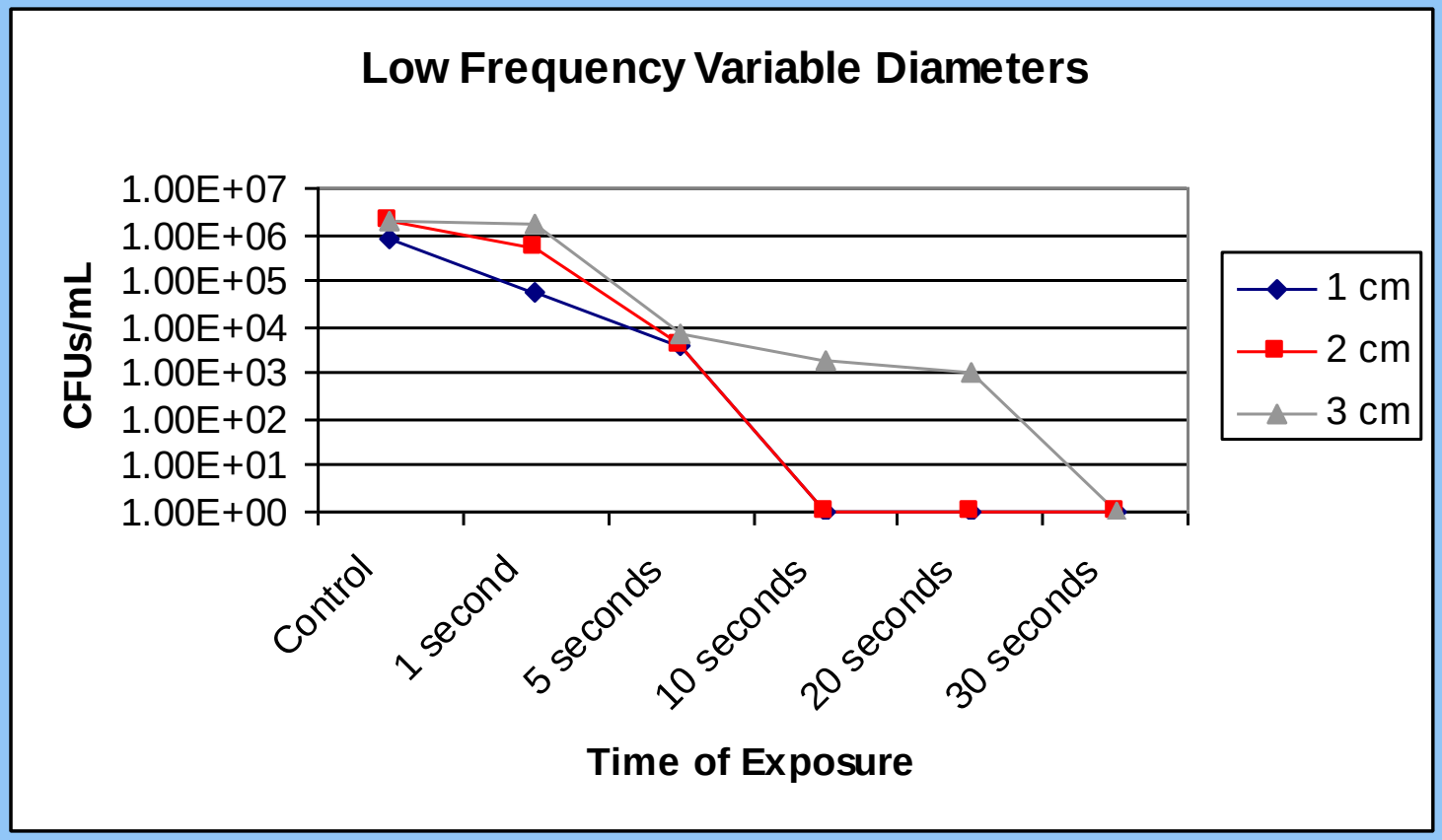


# Logarithmic Plot (Depth Variable)




*S. aureus* killed with 10 seconds plasma exposure

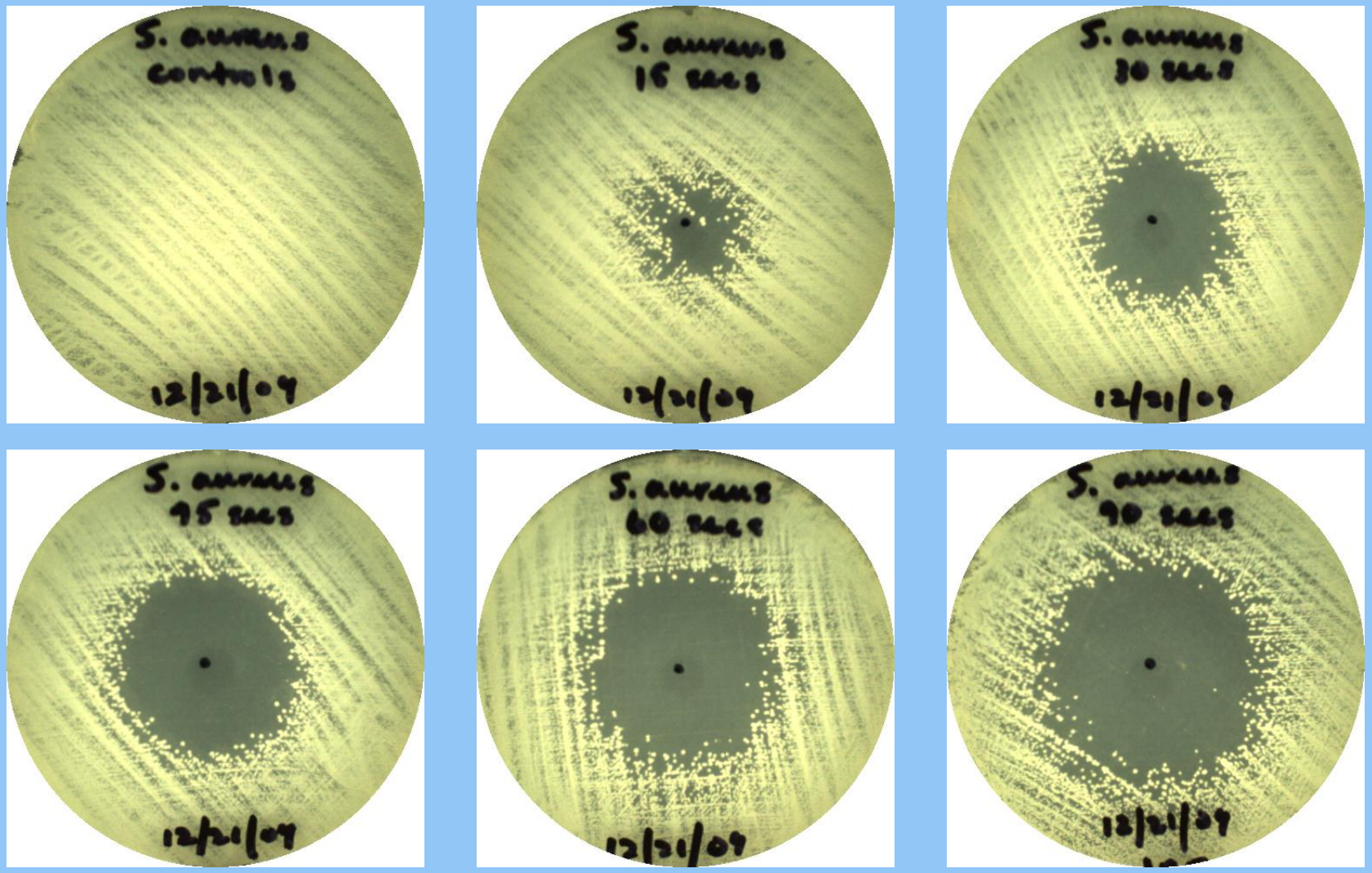
# Logarithmic Plot (Diameter Variable)



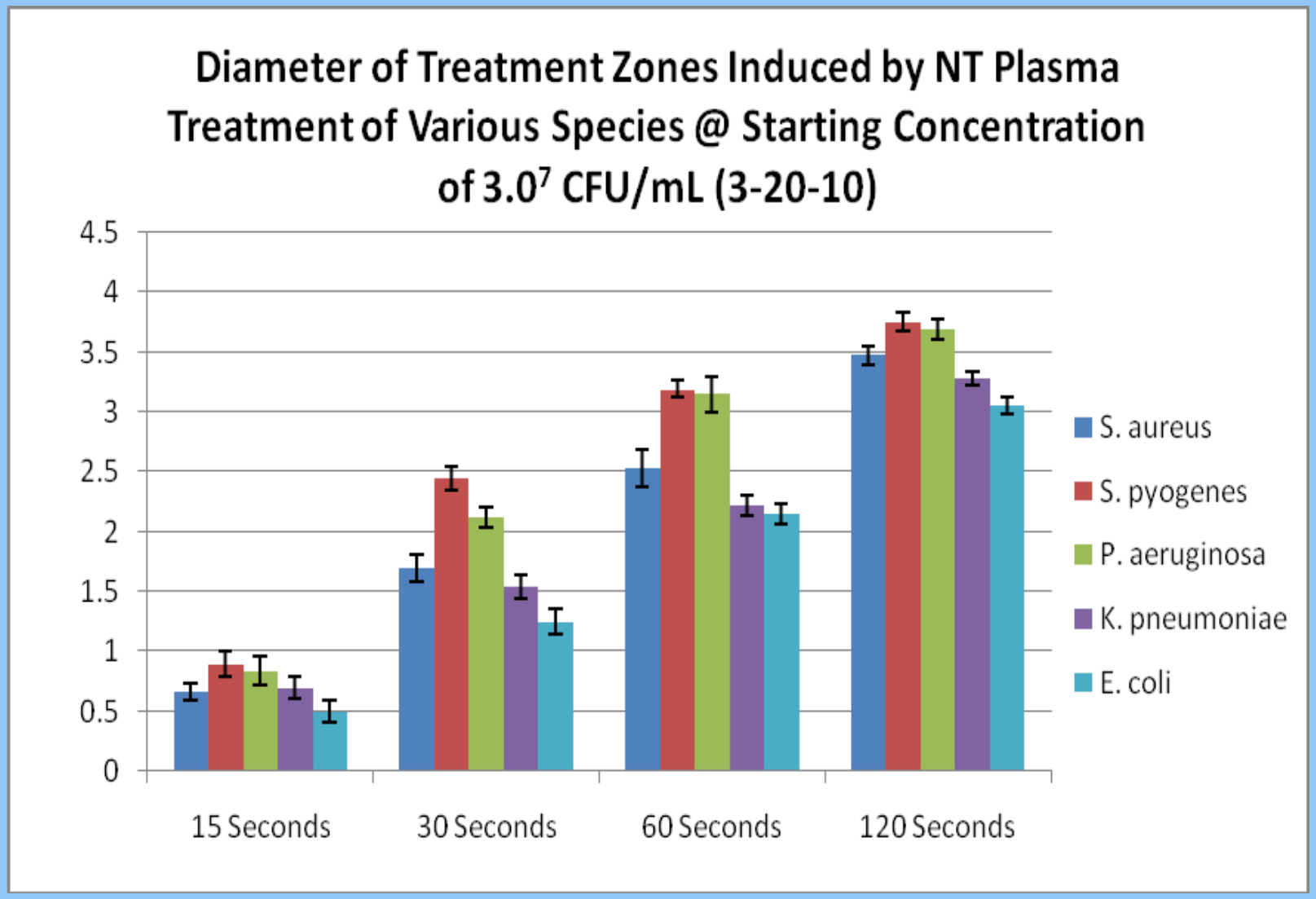

*S. aureus* killed with 30 sec plasma exposure

# Agar Plates (Diameter)

Bacteria streaked on TSA plates, treated and incubated

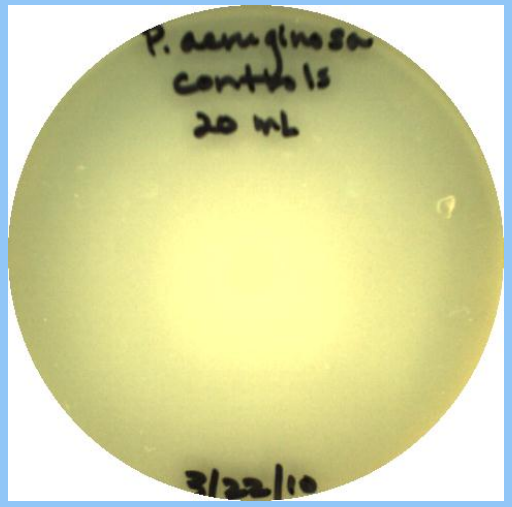


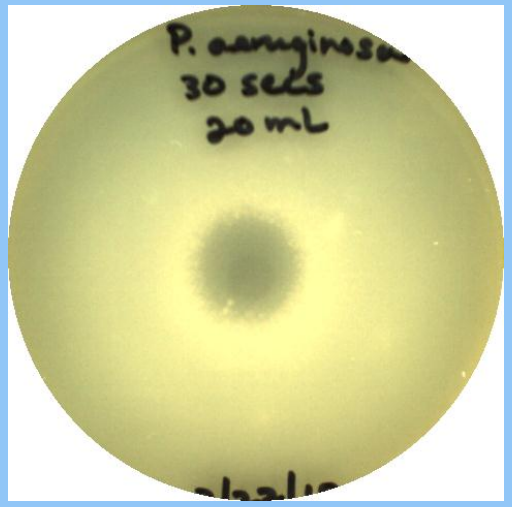
# Agar Plates (Diameter)

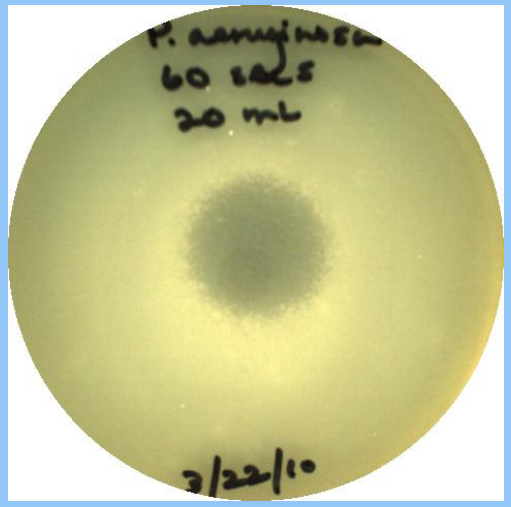


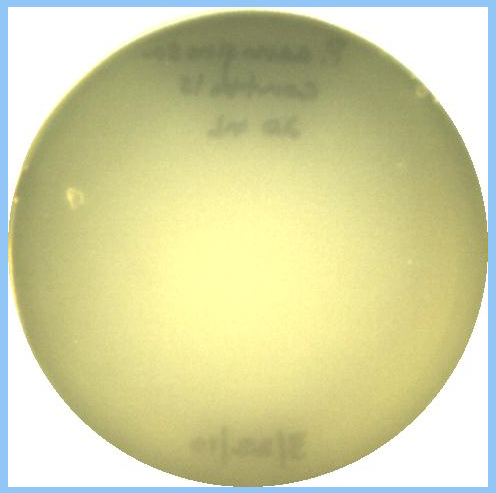
# Agar Plates (Penetration)

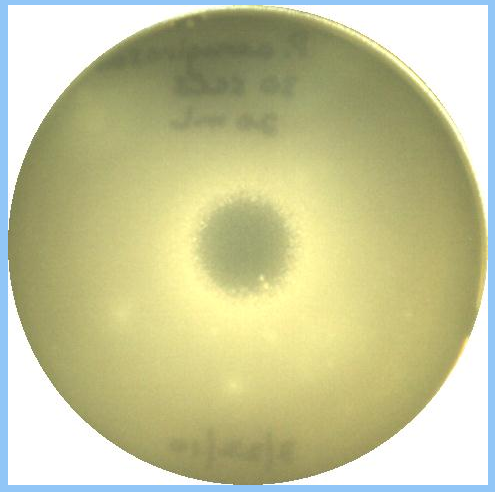
Bacteria suspended in TSA plates, treated and incubated

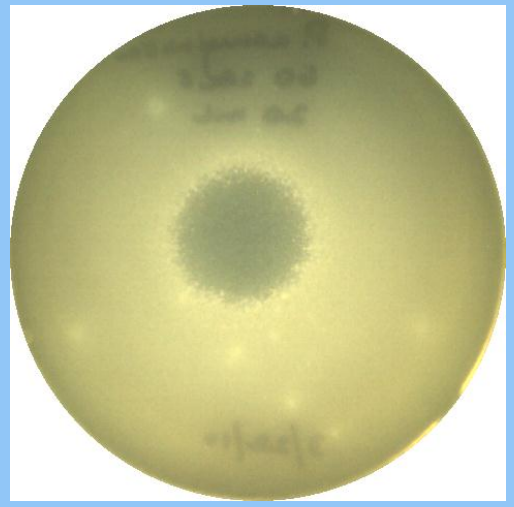


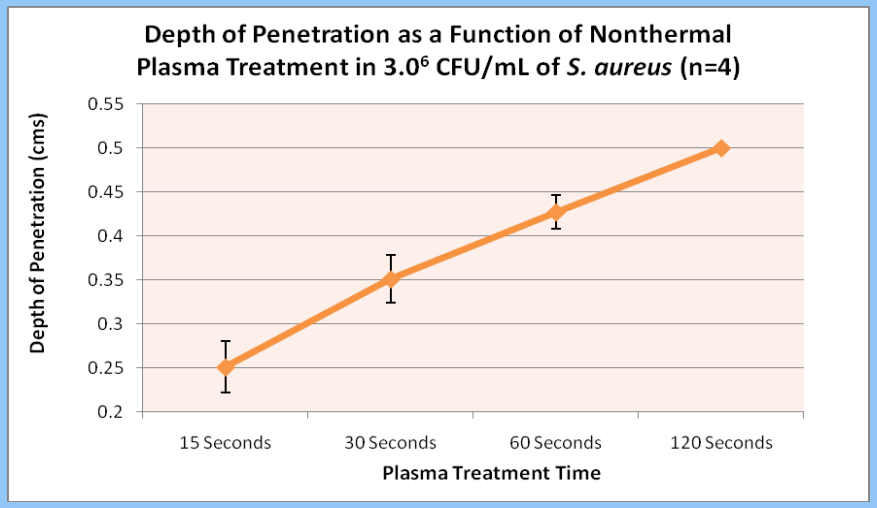





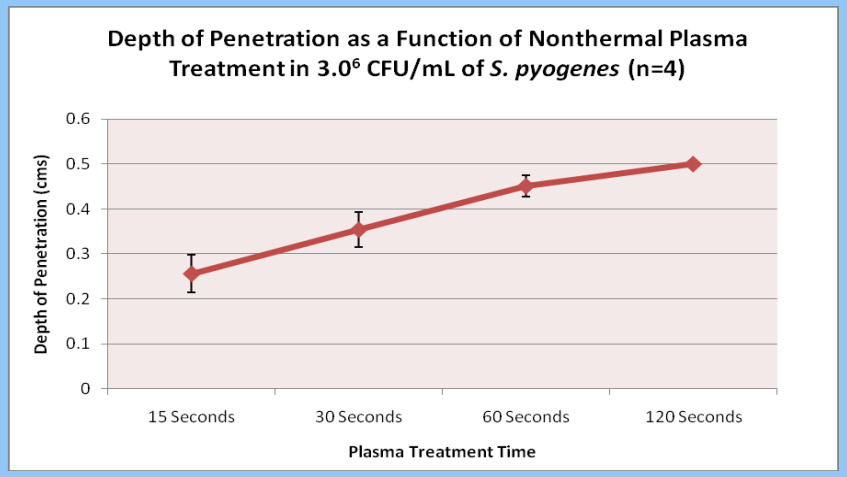


# Agar Plates (Penetration)

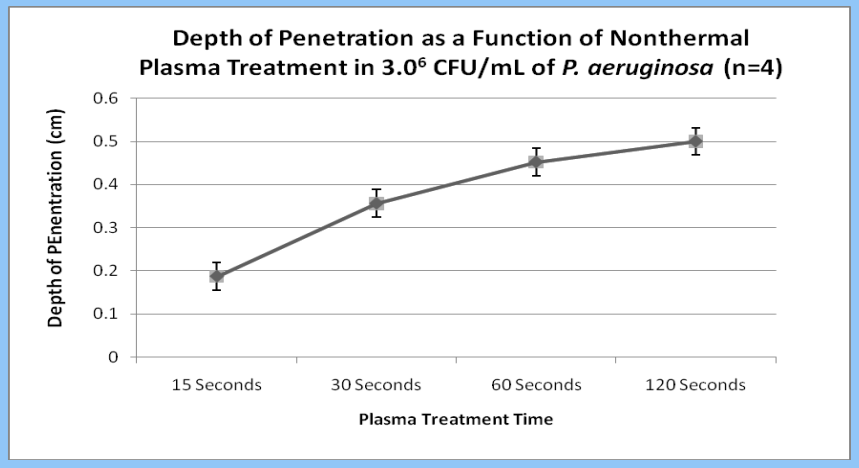
## *S. aureus*




## *S. pyogenes*

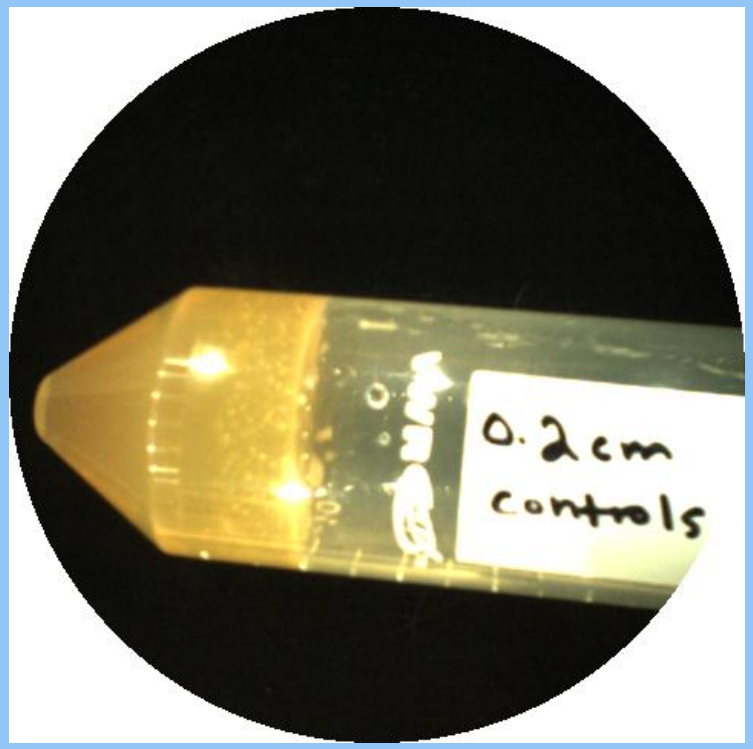


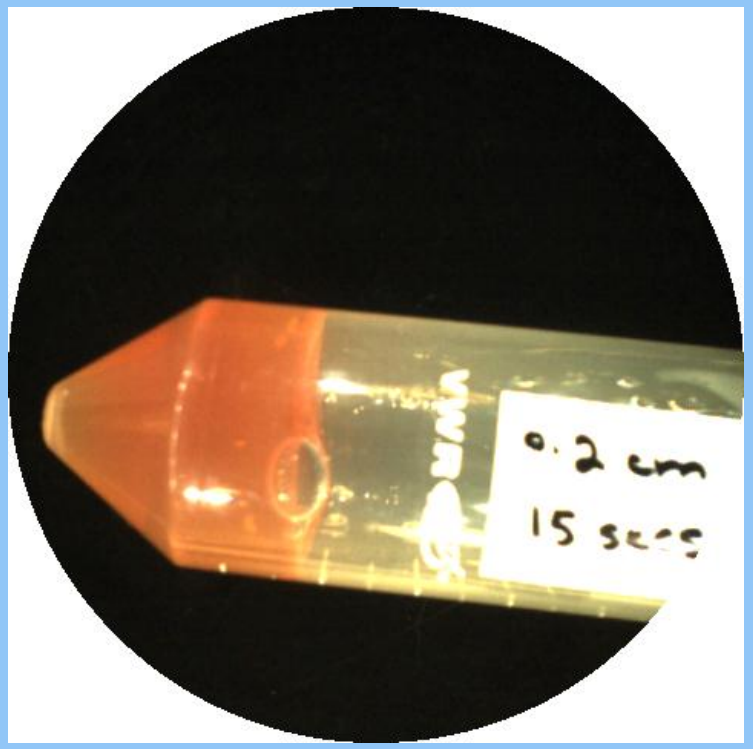

## *P. aeruginosa*



# Agar Penetration

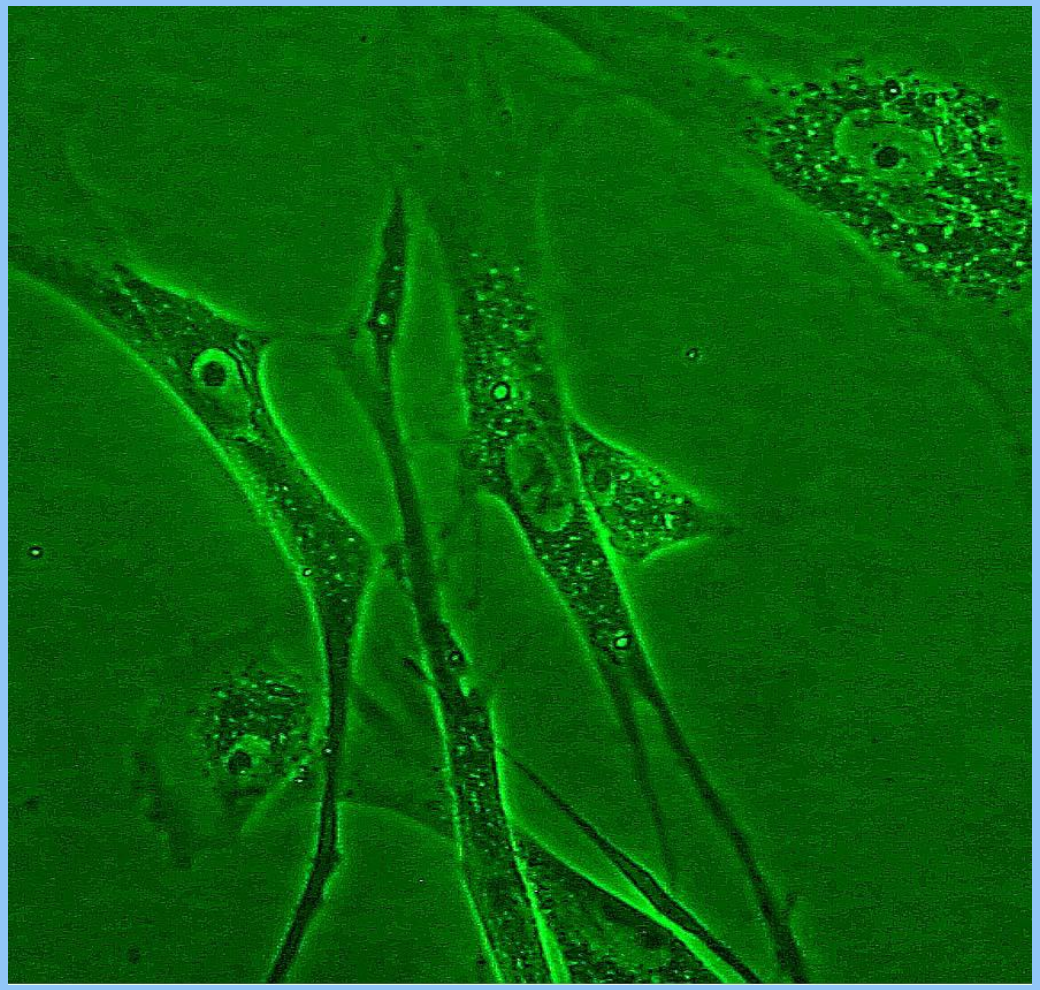
*S. aureus* suspended in TSA & layered on MSA



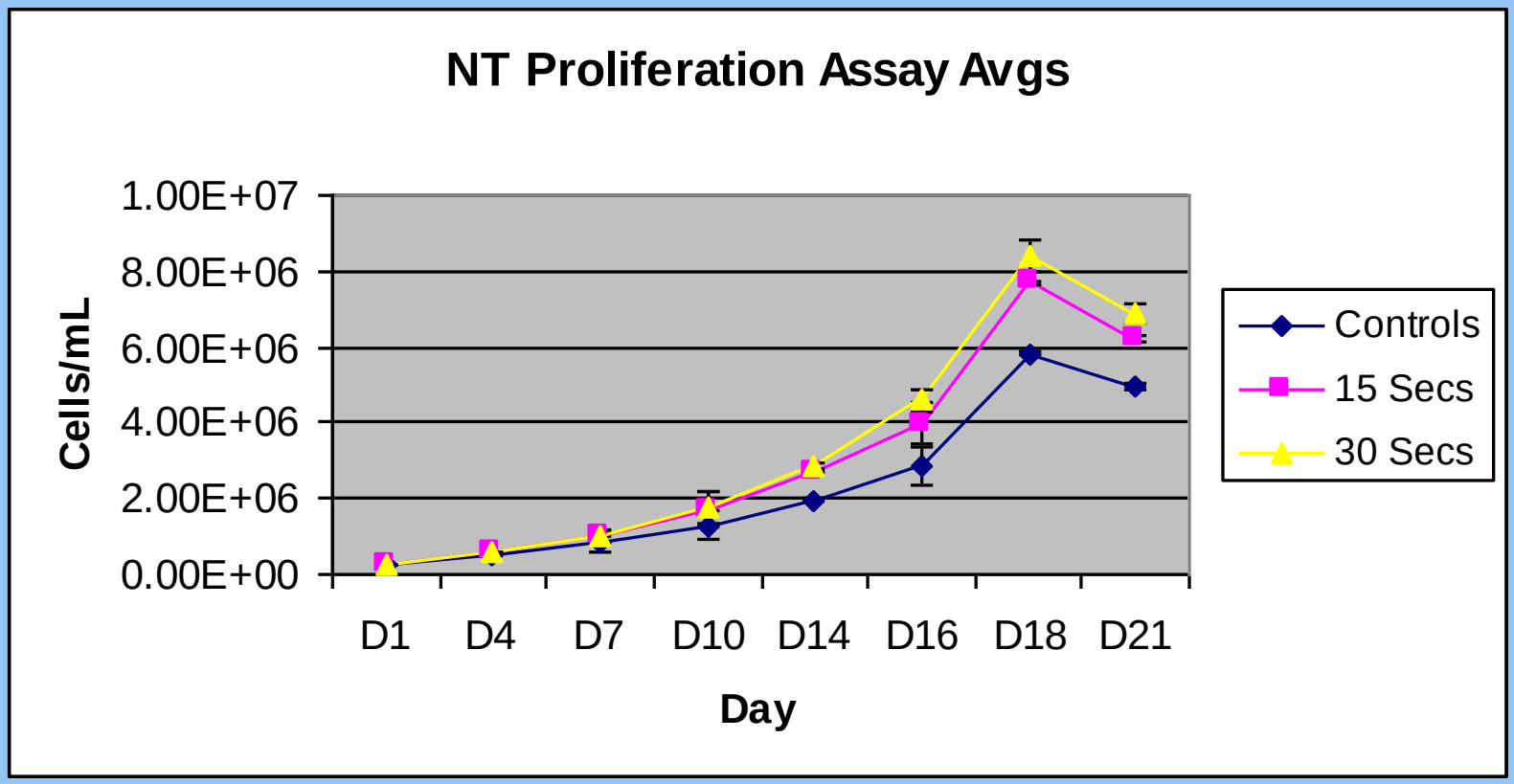



# *In Vitro* Cell Experiments

# Human Dermal Fibroblasts

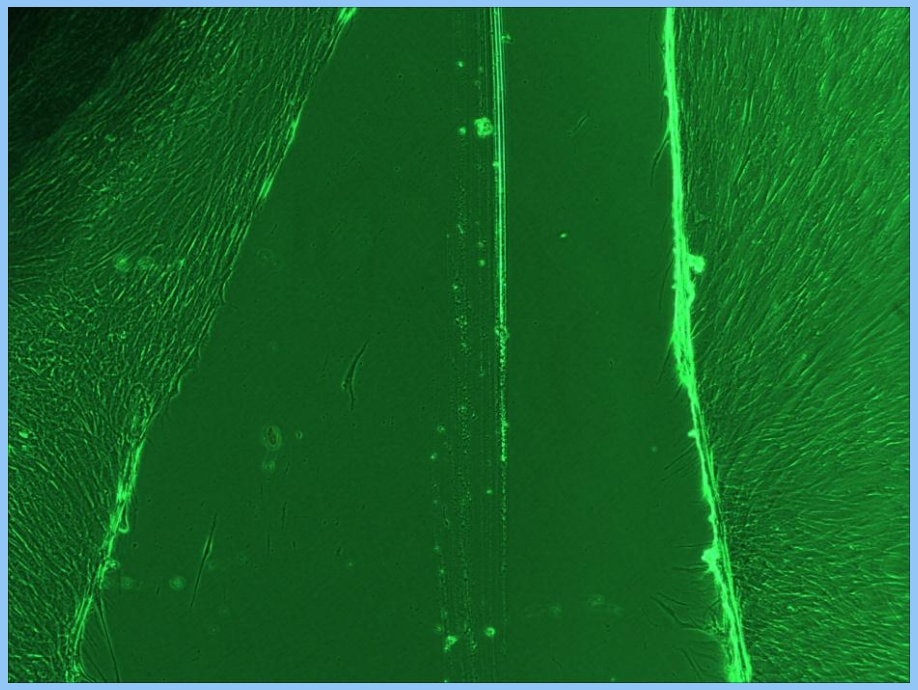


# Proliferation Assay

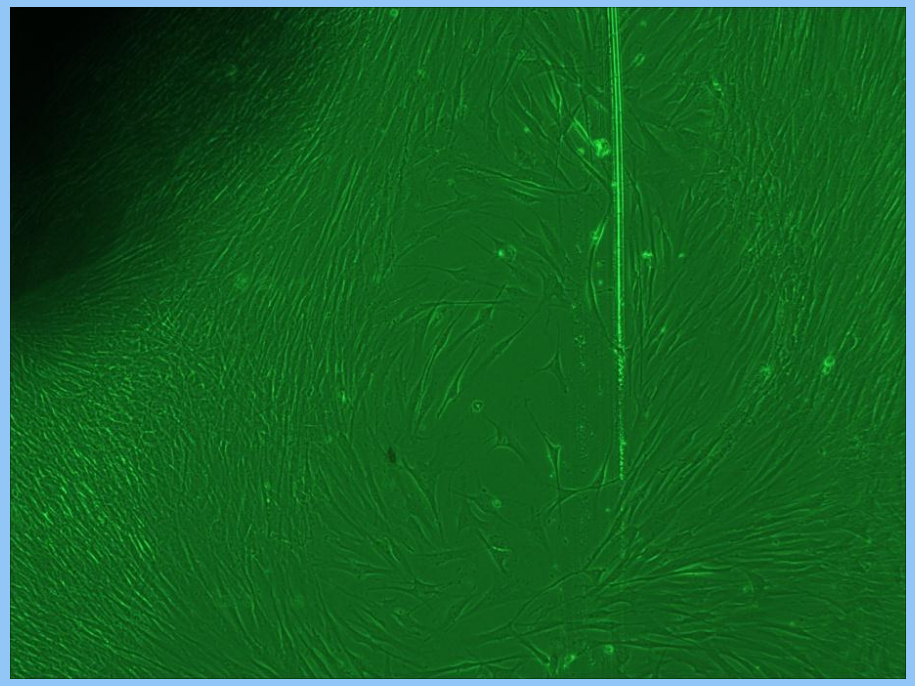



*P-values between controls and 15 seconds: P <0.05
*P-value between controls and 30 seconds: P <0.01

# Migration Assay

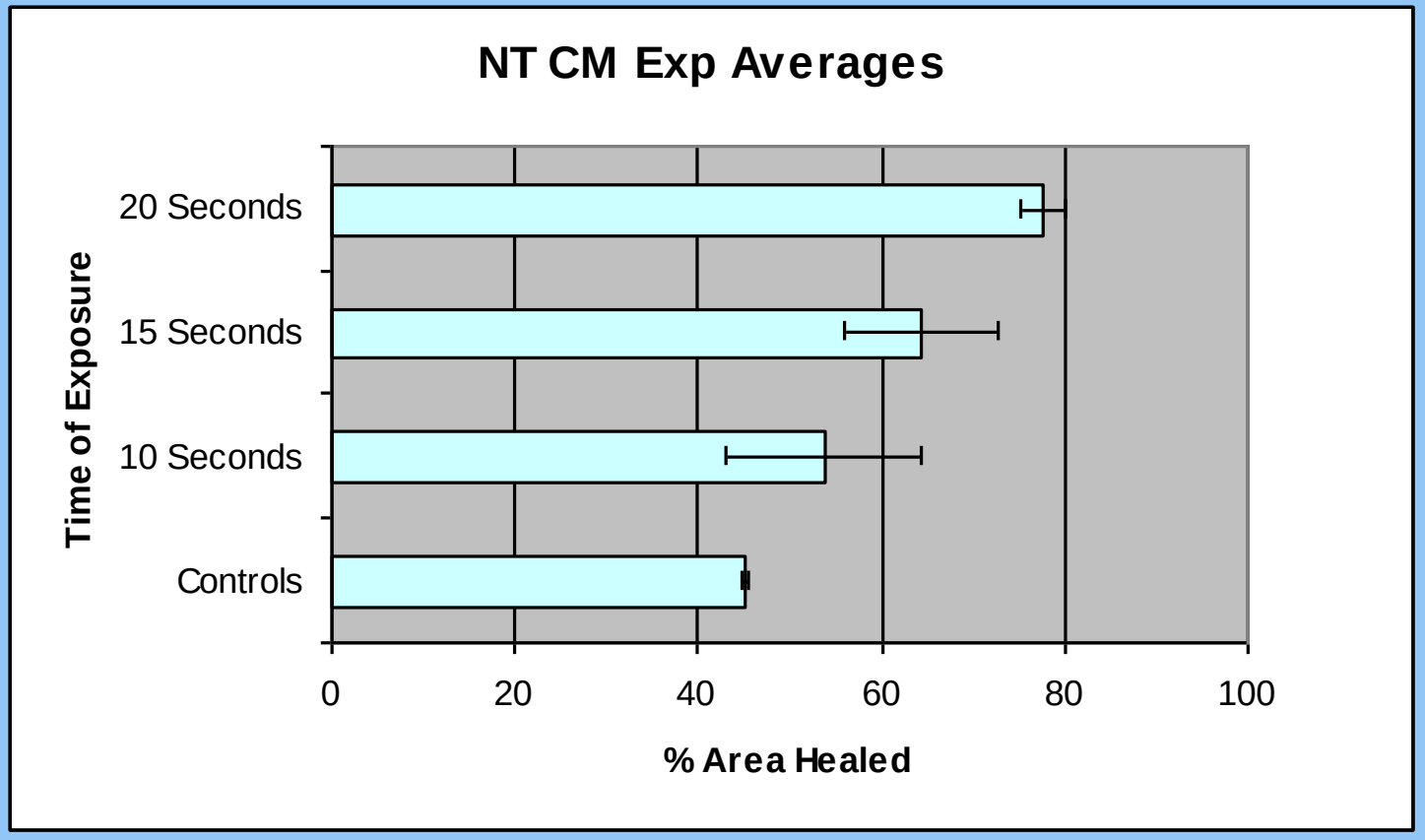


Time 0



24 hr

# Migration Assay



# Clinical Case Studies

# Diabetic foot

- Diabetic foot with gangrene
- Below-knee amputation indicated
- Conservative operation (heal-saving) was performed
- Application of cold plasma to the wound surface began right after surgery
- *No antibiotics or other treatment were used*

# Diabetic foot

Granulation – 7th day

Epithelization – 10th day

Full Healing – 18th day

- Cold Plasma treatment allowed leg-preserving amputation
- Healing 20 days earlier than in cases with standard treatment

# Bacterial Ulcerated Cornea Lesions

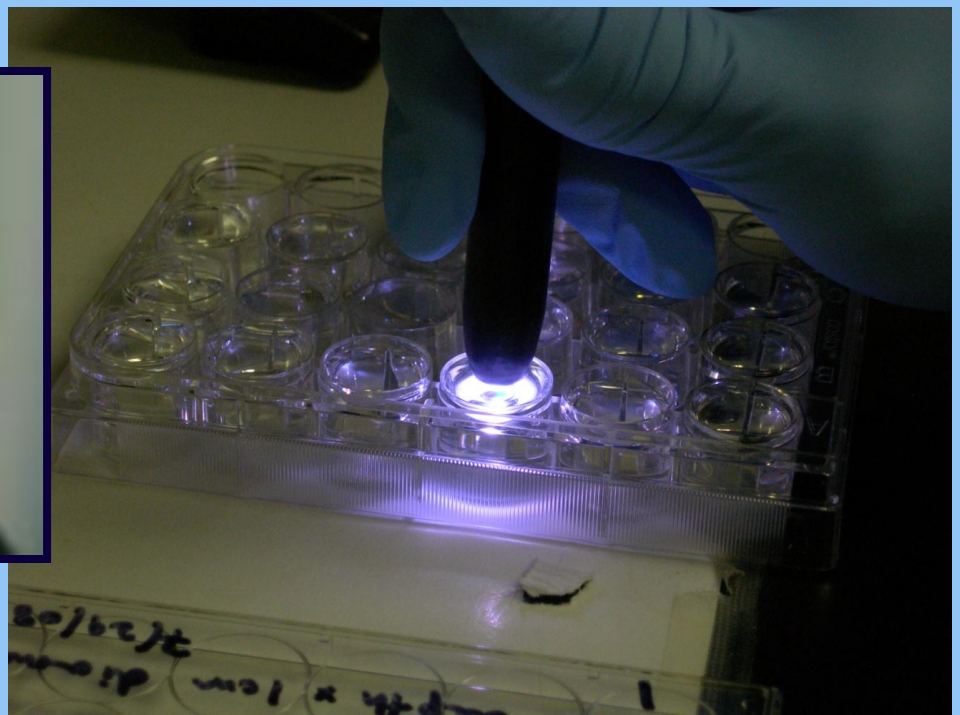
Before Treatment

Application of Cold Plasma

After Treatment

# Plasma Medicine

## An exciting new tool for wound healing



# Acknowledgements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- Aleksandr Galov – graduate student, Petrozavodsk State University
- Christopher Woolverton, PhD – Kent State University
- Bruce Banks – NASA (retired)
- Valentina Goutorova, MD et al. – Sterionics, Inc.

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- Sigma Xi Grant-in-Aid of Research
- Ohio Department of Defense grant Tech 09-006 (Clinical Tissue Engineering Center)