

Investigation of Magnetized DC Corona Discharge for Applications at Atmospheric Pressure

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Abstract

This project examines the non-equilibrium atmospheric pressure plasma (NEAPP) produced by a DC corona discharge system for use in biomedicine. Preliminary spectroscopic data collection and the development of a COMSOL model of the apparatus bring it closer to biological trials on cancerous cells and extremophilic bacteria.

Non-Equilibrium Atmospheric Pressure Plasma

NEAPP remains near room temperature and may be produced at atmospheric pressure by the application of an electric discharge to a gas [1]; a DC corona discharge system similar to [2] is used here for its cost-efficiency and safety. The discharge accelerates free electrons that ionize surrounding gas molecules, which typically cause additional ionizations before stabilizing and emitting excess energy as UV radiation. A new topic here is that plasma production might be optimized by the inclusion of an external magnetic field.

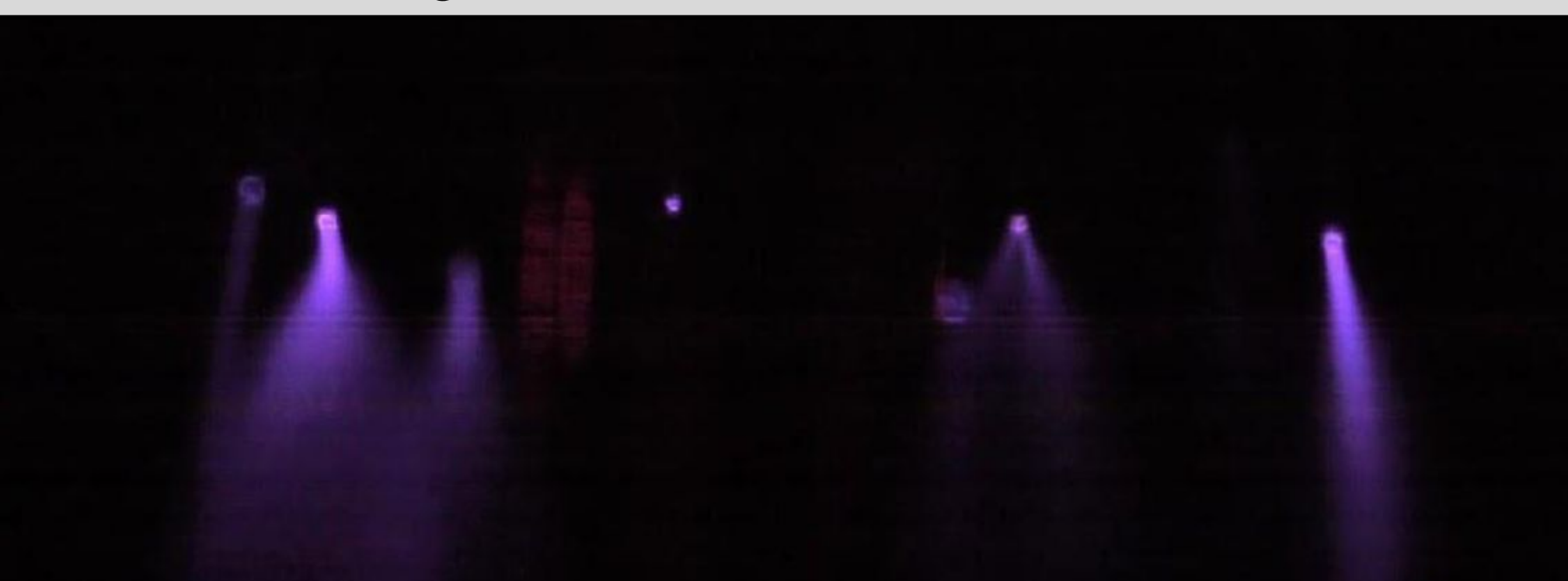


Figure 1. Discharge at multiple needle-tip electrodes from the apparatus in this project.

Biological Effects

The ionization of standard atmospheric gases tends to produce primary reactive oxygen and nitrogen species (RONS) such as superoxide radicals and nitric oxide [-]. If more than one reactive species is within proximity of another, they will react to form toxic secondary RONS (e.g., hydroxyl radicals, peroxyxynitrite) that can cause structural damage to molecules such as proteins, lipids, and DNA; substantial oxidative stress can lead to apoptosis or necrosis.

Applications and Benefits

NEAPP-producing devices are advantageous due to low assembly/operation costs, maneuverability, and overall safety. Applications include:

- Selective treatment of cancerous cells [3].
- Sterilization of viruses and multidrug-resistant bacteria [4,5].
- Decontamination and shelf-life extension of food products [6].
- Decontamination of spacecraft assembly facilities, where extremophilic microorganisms are capable of surviving or adapting to chemicals and radiation [7].

Apparatus Design and Variables

- Discharge is powered by a Gamma HV RR30-2R (+/- 0-30kV, 2mA, 60W) supply with reversible polarity.
- Voltage is adjustable by a 1-25MΩ resistor.
- The apparatus is surrounded by a cylindrical Plexiglass tube (7.5cm diameter).
- Voltage is applied to an electrode plate with 9 uniformly fixed stainless steel needles (20-gauge, 2" length; ~1 needle/5cm²), which pass through a Teflon insulator before reaching the discharge region.
- A grounded stainless steel mesh (initial data collection) or dish (biological trials) may sit below the discharge region to act as a second electrode.
- Gas will eventually be supplied at the top of the tube with enough pressure (adjustable flow rate) to reach the discharge region.

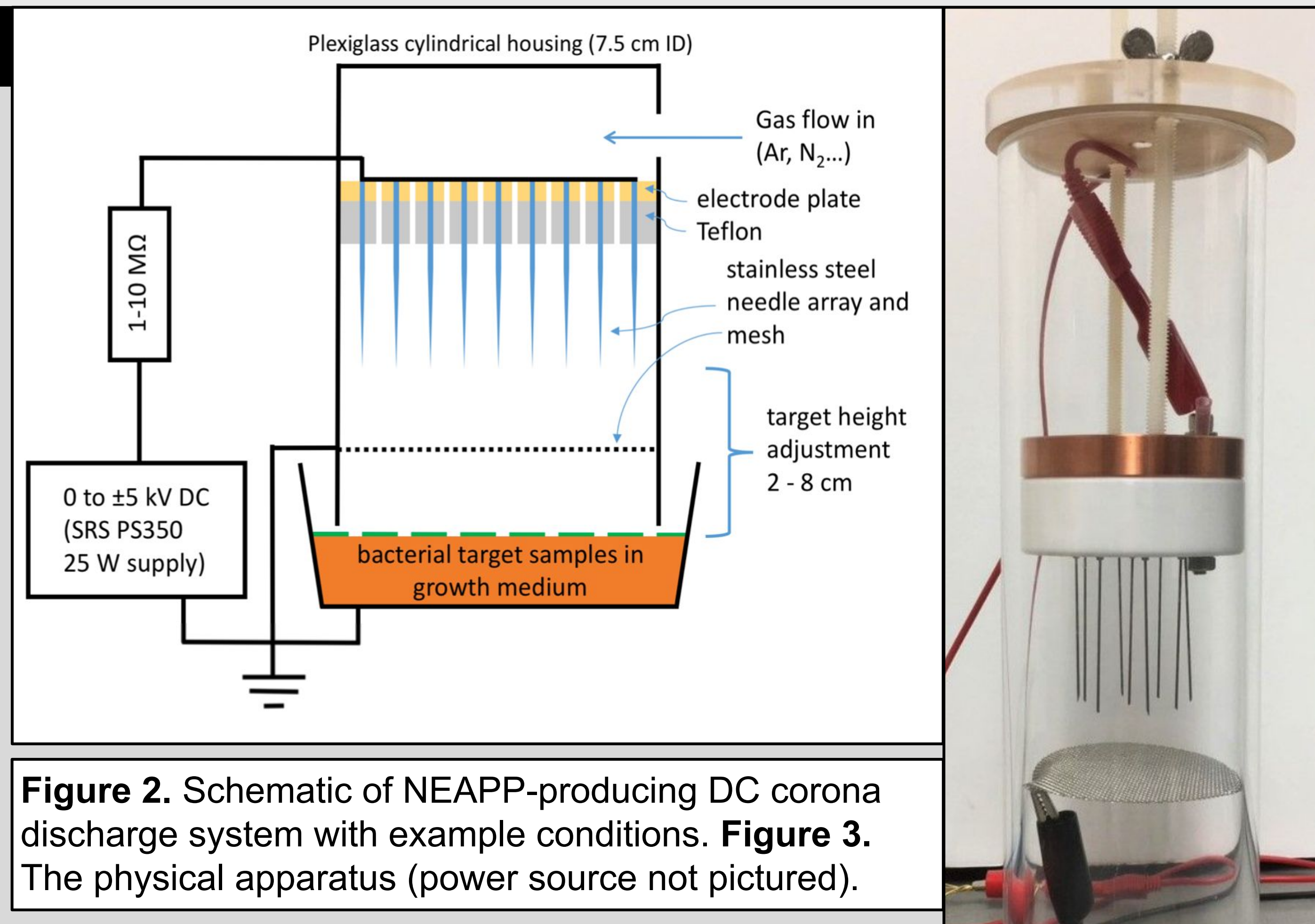
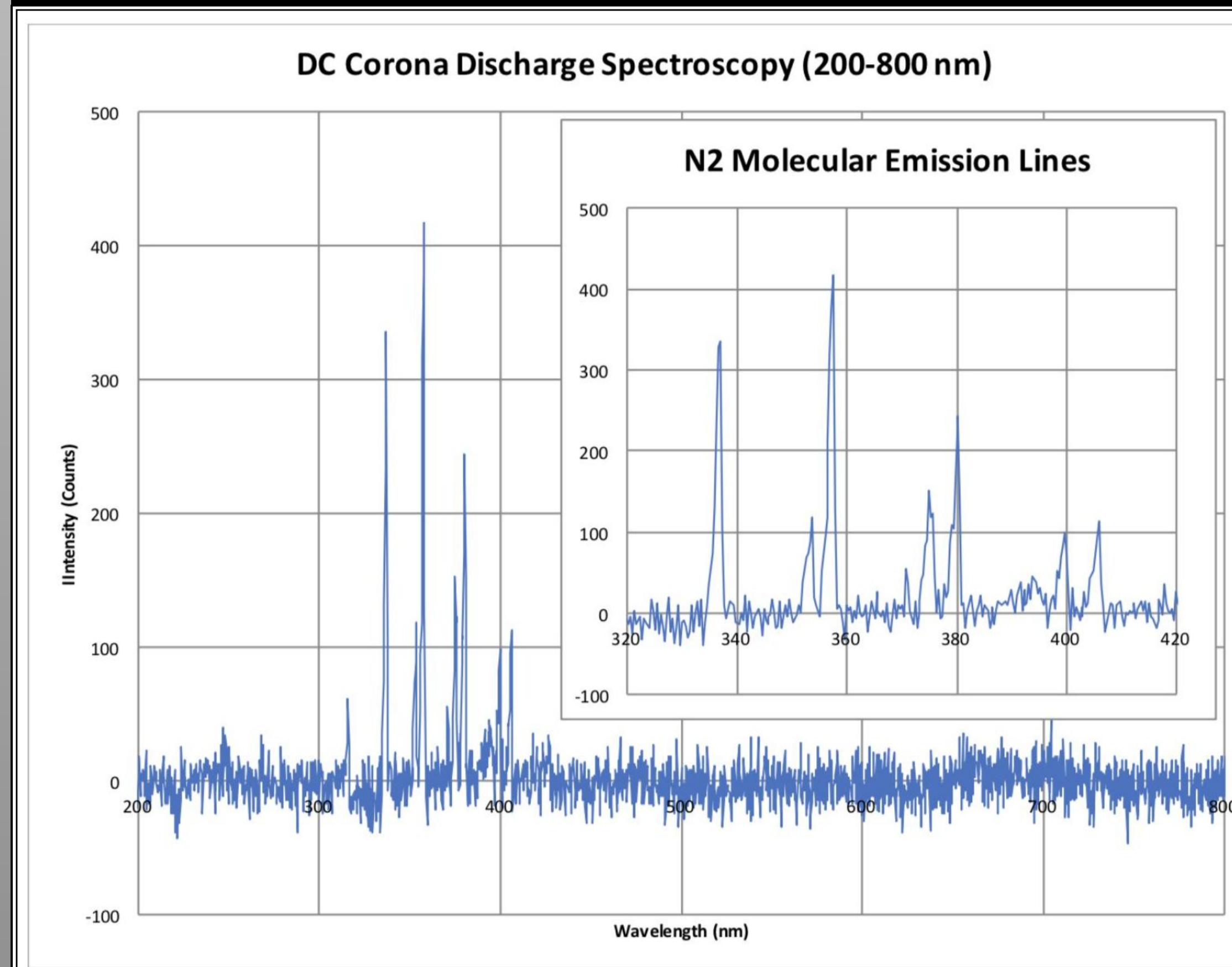


Figure 2. Schematic of NEAPP-producing DC corona discharge system with example conditions. **Figure 3.** The physical apparatus (power source not pictured).

Spectroscopic Tools and Initial Data



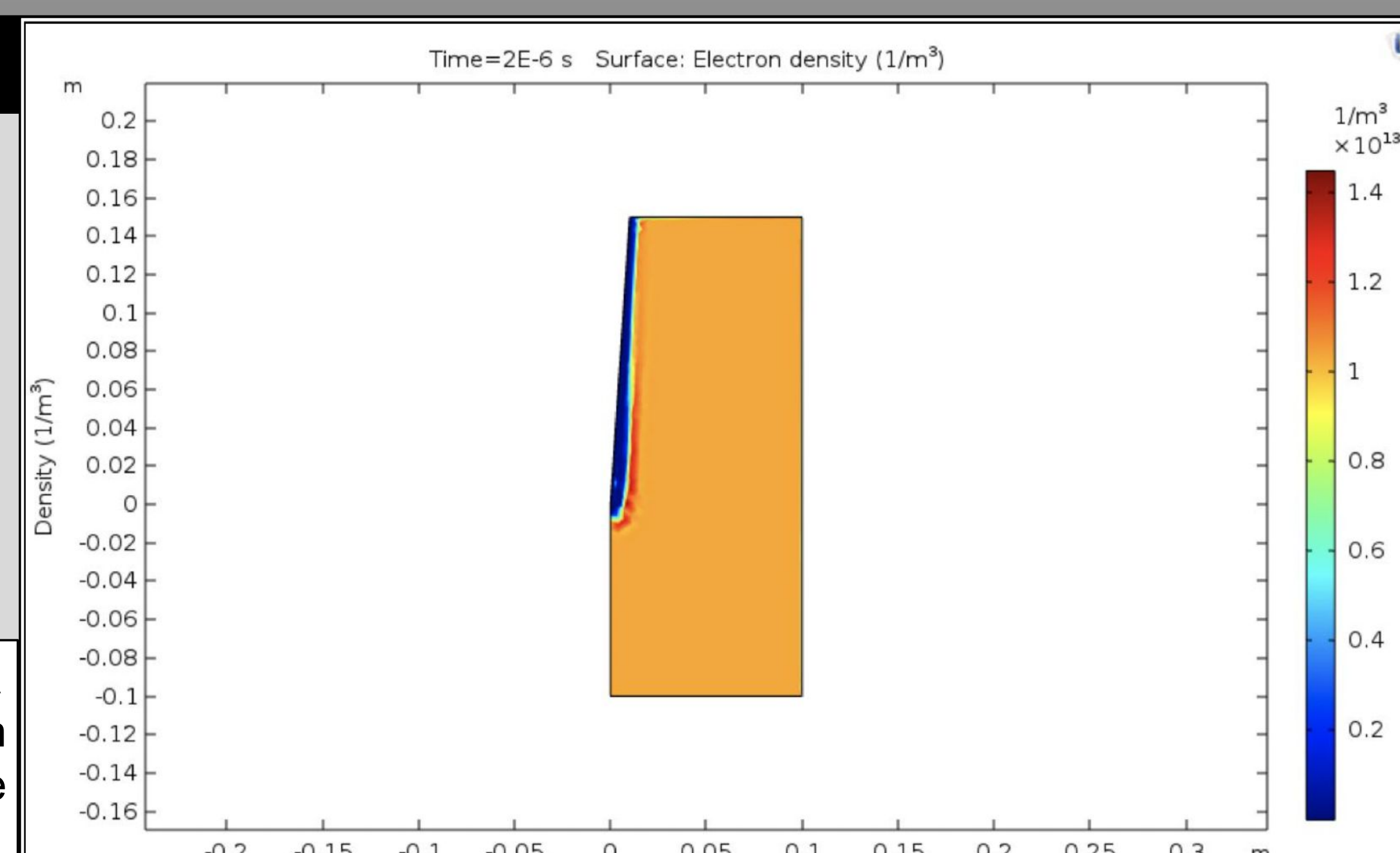
- Spectroscopic data collection and analysis will allow the correlation of specific species production with unique apparatus conditions.
- Initial observations of species production using an Ocean HDC spectrometer (200-950nm range, <1nm resolution) showed adequate signal-to-noise data acquisition.
- Vertical position and viewing chord of lens fiber are manually adjustable to optimize signal collection.
- Records of experimental conditions and spectroscopic data collection will later be automated by LabVIEW software with a built-in spectrometer interface.
- Observations using a Kron Chronos 1.4 high speed camera (>30,000fps) can be used to correlate spatial distribution of the discharge with varying RONS production.

Figure 4. Spectroscopic data acquired using the Ocean HDX spectrometer and the corona discharge apparatus (Fig.s 1,2). Discharge voltage of 15kV and current of 500μA were attained. Molecular nitrogen emission lines were resolved and identified in the data.

Simulation Tools and Model

Predictions of discharge behavior and chemical makeup will eventually be based on corona discharge simulations in COMSOL Multiphysics. Agreement between model and experimental results will allow the pursuit of more complex experimental conditions; disagreement will facilitate identification of erroneous instrument setup or environmental intrusion and/or model limitations. The current model features 3D elements of the apparatus and incorporation of an adjustable magnetic field.

Figure 5. 2D cylindrical (z vs. r) COMSOL simulation of a single "needle tip" electrode. Corona discharge is shown in the relatively high electron density (red contour) near the tip.



Proposed Apparatus Upgrades

- Adjustable gas feed
- Variable magnetic field produced by arrangement of neodymium magnets on a stainless steel process chamber surrounding the discharge apparatus

Future Work: Optimizing for Precision

Substantial simulation and spectroscopic data will be necessary to identify the ideal conditions for the production of specific RONS by the apparatus in this project. Adjustable variables include gas type, gas flow rate, relative distances between electrodes, voltage, current, and the surrounding magnetic field.

Future Work: Biological Trials

Precise biological effects of the RONS produced by this apparatus will be investigated by exposure of different cell types to the plasma discharge. Anticipated cell types include cancerous A549 cells and *Deinococcus radiodurans*, an extremely radiation-resistant bacterium. The apparatus will be assessed for efficiency and efficacy of sterilization; cell apoptosis or necrosis will be quantified by the number of colony-forming units following treatment. Conditions may be selected so as to also observe treatment effects when specific RONS are produced, i.e., which RONS may be best suited to sterilize different cell types. Scanning electron microscopy may also be used to visualize cell damage if present.

Conclusion

The NEAPP apparatus in this project has been constructed and its discharge has been spectroscopically observed; initial simulations have been run. Future work will focus on refinement of both model and apparatus, as well as automated spectroscopic data collection.

Acknowledgements

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- *Particle-in-Cell / Fluid Simulation of Atmospheric Pressure Plasma Corona Discharge* | 11:00AM-12:00PM | Katherine Sakeagak