

The Biomedical Applications of Plasma: A Brief History of the Development of a New Field of Research

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Abstract—This paper is an essay narrating the recent history of the introduction of the biomedical applications of nonthermal plasmas to the plasma science research community.

Index Terms—Atmospheric pressure, bacteria, biomedical, cold plasma, electrical discharge, eukaryote, nonthermal plasma, sterilization.

ON THE occasion of the publishing of this fifth Special Issue of the TRANSACTIONS ON PLASMA SCIENCE (TPS) on the medical, biological, and environmental applications of plasmas, I thought it is time to write a brief historic essay on how plasmas entered biomedical research and how biomedical applications of plasmas became a mainstream topic in plasma-based conferences and journals. It is very fitting to publish such an essay in an IEEE Nuclear and Plasma Science Society (NPSS) Journal, since it is at an IEEE-NPSS-sponsored conference [International Conference on Plasma Science (ICOPS)] that the topic of the biomedical applications of plasma first found a home. Moreover, some of the seminal papers in this field were published in this very journal (TPS).

Historically, plasmas were first employed in a “biological” application in the late 1850s when Siemens used a dielectric-barrier discharge to generate ozone and used the ozone to clean water from biological contaminants. However, no systematic research was conducted to understand the interaction between plasmas and biological cells until more than 130 years later, in the mid-1990s. In the meantime, some attempts were made to use plasmas for biological sterilization from the 1960s to the 1980s [1]–[3]. However, most of these experiments used plasma as a secondary agent in the sterilization process, and no scientific investigations were made to understand how plasma actually interacted with bacterial cells and how it caused their demise. It is only until the mid-1990s, when atmospheric-pressure nonequilibrium plasmas became a “hot” research topic, that investigations aimed at elucidating the effects of plasmas on bacterial cells were initiated [4]–[14]. The people that were involved in these early attempts were very few, so limited knowledge was generated at those early days, but many of the pertinent issues were identified. It is also noteworthy to mention here that parallel efforts using low-pressure plasmas

took place in the late 1990s [15], [16] and that, in the early 1990s, a group at Los Alamos National Laboratory studied laser-produced plasmas for medical applications including in ophthalmology, urology, and cardiology [17].

Since this new research topic of biomedical applications of plasmas was at its infancy in the early and mid-1990s, particularly in the case of atmospheric plasmas, not many people in the scientific community were aware of this work and funding was practically nonexistent. So most of us who were involved in this research were doing it on the side, out of scientific curiosity, and without the benefit of external funding. Then came 1997, a pivotal year for the U.S. researchers. This was the year when the first funding for this kind of multidisciplinary research that bridged physics and biology started. This initial funding was provided by the Electronics and Physics Directorate of the U.S. Air Force Office of Scientific Research (AFOSR) under a small business technology transfer program directed by Dr. Robert J. Barker. A few university researchers in collaboration with small companies were given small amounts of funding, mainly to develop a proof of principle and show that cold atmospheric-pressure plasma can be used to destroy biological/chemical contaminants effectively. By early 1998, the few groups funded by this AFOSR program started generating interesting results. Dr. Barker and myself then discussed the idea to generate interest in a conference session where results from the AFOSR program would be presented. The IEEE ICOPS was our home conference, and it was natural to select it as a candidate to hold such a session. The upcoming ICOPS at that time was to be held in Raleigh, NC, in June 1998. Unfortunately, sessions were already set and approved by the Executive Committee of the Plasma Science and Applications Standing Technical Committee, and a “biological applications of plasmas” session simply did not exist. To go around this issue, Prof. John Scharer (University of Wisconsin, Madison) who ran the session on the microwave interactions with plasma offered us one of his session slots (he had two slots) where we put all the oral papers dealing the biological applications of plasmas. I personally chaired the session, which had only three oral presentations on the topic. Therefore, effectively, ICOPS 1998 held the first session dedicated to disseminating the first results of a coordinated effort to investigate plasma–cells interactions. In a few years time, all major international plasma conferences followed suit and added the biological/medical applications of plasmas to their technical topics’ repertoire. Of note among these conferences are the Gaseous Electronics Conference,

Manuscript received November 13, 2007.

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Digital Object Identifier 10.1109/TPS.2008.917167

the International Conference on Phenomena in Ionized Gases, and the International Symposium on Plasma Chemistry. In addition, both in the U.S. and in Europe, several workshops and miniconferences were organized around this topic. Of note are the Electromed Conference series, which were held in 1999, 2001, 2003, and 2005 in the U.S. The Electromed Conference series were mainly sponsored by AFOSR. The conferences organizers and locations were as follows: R. J. Barker, K. H. Schoenbach, and S. Liu, Norfolk, VA, 1999; S. Beebe, J. Birmingham, and K. H. Schoenbach, Portsmouth, VA, 2001; M. Murphy, San Antonio, TX, 2003; J. G. Birmingham, T. E. Johnson, and M. Laroussi, Portland, OR, 2005. Four Special Issues of the IEEE TRANSACTIONS ON PLASMA SCIENCE (TPS Vol. 28, No. 1; Vol. 30, No. 4; Vol. 32, No. 4; and Vol. 34, No. 4) were published, respectively, in 2000, 2002, 2004, and 2006 based mainly on papers presented at the Electromed Conferences. These Special Issues were managed by "guest editors" proposed by the conference organizers and approved by S. J. Gitomer, the Editor-in-Chief of TPS. The guest editors were K. H. Schoenbach, R. J. Barker, and S. Liu for the 2000 issue, M. Laroussi and S. Beebe for the 2002 issue, R. P. Joshi, A. G. Pakhomov, and W. R. Rogers for the 2004 issue, and J. F. Kolb, M. G. Kong, and P. F. Blackmore for the 2006 issue. In due time, other journals followed suit and also published Special Issues (under a variety of titles) on the biomedical applications of plasmas. Of note are the issues published by *Plasma Processes and Polymers* (Vol. 3, No. 6/7, 2006) and *Journal of Physics D: Applied Physics* (Vol. 39, No. 16, 2006). It is fitting at this juncture to mention that, through the years, the session at ICOPS that started with mere few papers in 1998 grew to become one of the largest sessions of the conference with a typical number of submissions around 60. Having organized many of these sessions myself, I feel great satisfaction to see this field grow at such a pace. Not only have conferences and journals adopted the topic of the biomedical applications of plasmas but also, soon after AFOSR initiated a funded program on the topic in 1997, other agencies joined the impetus and started funding similar research programs. Among these are the National Science Foundation, the U.S. Environmental Protection Agency, and the Defense Advanced Research Projects Agency. Most recently, in 2005, the European Commission funded a research program named BIODECON involving a partnership of research laboratories in Germany (Ruhr University, Bochum, and The Fraunhofer Institute, Munich), Italy (Joint Research Center, Ispra), and France (Commissariat à l'Énergie Atomique).

Today, research has expanded to include work on the interaction of plasma with eukaryotic cells, such as mammalian cells, with potential applications in wound healing and in fighting some types of cancers by inducing apoptosis (programmed cell death). These are exciting applications that could take plasmas further into the medical and therapeutic fields. Already, at the time of the writing of this essay, the first International Conference on Plasma Medicine, chaired by Prof. Alexander Fridman of Drexel University, took place in Corpus Christi, TX (October 15–18, 2007), where such novel applications were discussed. To conclude this essay, I would like to point out that ICOPS as a conference, TPS as a journal, and AFOSR as a

research-funding agency were instrumental in bringing to the forefront a new and exciting field of scientific research. Without their timely support, their encouragements to the preliminary efforts of the few researchers active in the field back in the mid-1990s, as well as their willingness to disseminate the results coming out of these works, these early efforts may have gone unnoticed. Finally, I would like to quote an excerpt from the introductory paragraph of the abstract of the plenary talk titled "Plasma and Pulsed Power for Biomedical Applications" that R. J. Barker gave at ICOPS 2000 [18]. In my opinion, this excerpt summarizes very well what was going at that time: "A quiet yet dramatic revolution is invading the ultraconservative domain of western medicine. Virtual guerilla bands of visionary physicists and engineers are threatening to overturn conventional wisdom and challenge common practice in fields held hostage for centuries by chemists and biologists. We will examine the historical scientific roots of this insurgency, comment on its current manifestation, and speculate about its exciting future."

ACKNOWLEDGMENT

I would like to thank the guest editors of this Special Issue for being receptive to the idea of having this essay published to commemorate the fifth issue of its kind. I also would like to thank S. Gitomer, the Editor-in-Chief of TPS, for appreciating the early work on the topic, for taking the initiative to publish the early papers in this journal, and for being instrumental in establishing this series of Special Issues.

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