about Plasmas
from the Coalition for Plasma Science

Destroying Biological Hazards

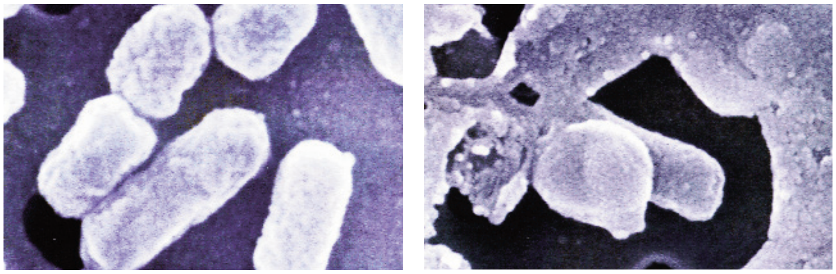
Anthrax. Mad Cow Disease. Biological Weapons. These words have filled headlines, increasing anxiety around the world. The threat of such biological hazards, both natural and man-made, has created unprecedented challenges for public health institutions and hospitals, as well as for national defense. These biohazards demand fast and effective decontamination techniques.

Plasmas fill most of the universe and are used in our daily lives. For most plasmas, however, we can get close but cannot touch. This plasma streamer is an example. Some atmospheric-pressure plasmas that might be used for destroying germs are exceptions.

Conventional techniques, which rely on chemicals and/or extreme heat, are not suitable in many situations. They do not fully address the challenges of sterilizing heat-sensitive medical tools; decontaminating protective gear and electronic equipment; or destroying heat-resistant micro-organisms such as the protein that causes "mad cow disease." To address these short-comings scientists have been exploring the use of plasma as a decontamination agent.

Plasma is formed when enough energy is added to a gas to free electrons from a significant number of atoms or molecules. This process, known as "ionization," creates a mixture of positively charged particles (ions), negatively charged particles (electrons) and various uncharged particles. Among these particles can be high concentrations of so-called free radicals, atomic or molecular fragments that are very chemically reactive. These free radicals can quickly overwhelm the natural defenses of living organisms, leading to their destruction. Because plasma can easily produce above half a trillion (i.e., 500,000,000,000) free radicals per cubic centimeter volume, it can be an efficient decontamination agent.

Using free radicals is not the only way plasmas can kill germs. Plasmas also produce electromagnetic radiation, including ultraviolet (UV) light. The ultraviolet light sterilizes in a different way, by causing DNA damage. Furthermore, scientists have observed that bacterial cell membranes sometimes rupture when exposed to plasma. This may be caused by charged particles attaching to the outer surface of the cell, inducing an electrostatic force that can overcome the tensile strength of the cell's membrane, rupturing it.



Micrographs of E. coli cells before plasma treatment (left) and after (right). The plasma-treated sample on the right clearly shows morphological damage to the E. coli cells.

Researchers have developed several novel ways of producing plasmas that are suitable for sterilization and decontamination. These plasmas are "cold" in the sense that the temperature of the plasma-forming gas remains close to room temperature. Consequently the plasma does not damage the surfaces it contacts. These new approaches also have the ability to produce relatively large volumes of cold plasma at atmospheric pressure, even in

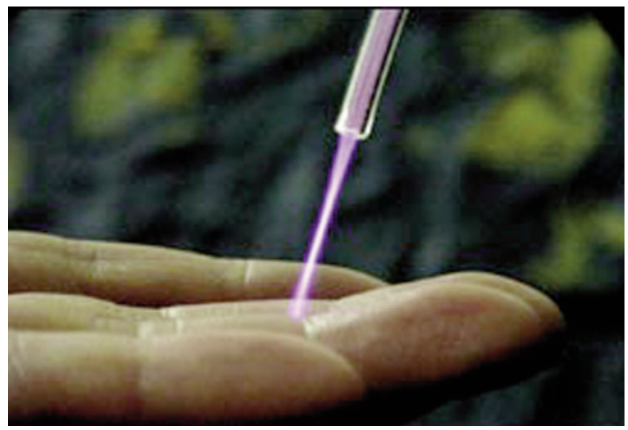
Continued on back

open air. Using an open air plasma eliminates the need for expensive and cumbersome chambers like those used to lower the pressure and control gas mixtures for many industrial applications, such as fabricating computer chips.

Scientists have found that high concentrations of bacteria can be killed after being exposed to a plasma for as little as ten seconds. This includes spore-forming bacteria, such as *Bacillus subtilis,* which survive harsh environments by forming a protective shell around their cells, and non-spore-forming bacteria such as *Escherechia coli* (*E. coli*). Tests have shown that plasma can neutralize microorganisms similar to anthrax (*Bacillus anthracis*), which is spore-forming.

These results show that cold plasmas can be effective for a number of applications. Heat-sensitive medical tools that would be destroyed by the high temperatures of steam autoclaves are sterilized by plasmas without damage. Compared with ethylene oxide, a toxic gas often used for low-temperature decontamination, plasmas are also advantageous because their decontamination processes do not leave toxic residues. Furthermore, plasmas can decontaminate food packaging (for safety and longer shelf life), as well as surfaces exposed to biological warfare agents. Cold plasmas are especially effective for these applications because they can treat contaminated items relatively quickly.

Plasmas are also effective because they can diffuse into complicated structures, such as endoscopes, in much the same way as ethylene oxide, but without that decontaminant's undesirable toxicity. This property makes plasma decontamination more effective than methods based on radiation beams (e.g., gamma rays, electrons, UV light), which are all limited by where the beam is directed. When required, however, a plasma can be directed, as pictured at the right. Such a plasma stream can easily be used to sterilize the internal surface of a long catheter (e.g., 20 cm long, the size often used in surgery).


An atmospheric plasma flows onto a hand without causing injury.

Improved techniques need to be developed to inactivate heat-resistant bacteria and viruses. Plasma shows promise for destroying prion, the protein behind "mad cow disease," which cannot be killed with any conventional sterilization technique. The difficulty of killing heat-resistant organisms like prion limits healthcare institutions to single-use surgical instruments, an option that is not economically sustainable, given that the annual bill for single-use surgical instruments exceeds a billion dollars worldwide.

Plasma also has potential on the battlefield. The military has been considering using plasma to decontaminate gear and equipment of forward-deployed troops who may be exposed to biological warfare agents. In addition, plasma may be used to sterilize medical tools rapidly in makeshift hospitals near the harsh environments of battlefields.

The development of cold atmospheric plasmas offers new hope for destroying stubborn bacteria and viruses, both for defense and public health. Atmospheric plasma decontamination also brings considerable economic benefit. For example, the material cost of a decontamination unit for a hospital is likely to be at least ten times less expensive than comparable low-temperature decontamination systems currently used in healthcare. Clearly, both in terms of effectiveness and low cost, the future of plasma decontamination is bright.

Suggested Reading:
M. Laroussi, IEEE Trans. Plasma Science., vol.24, no.3, pp. 1188-1191, 1996.
H. Herrmann, I. Henins, J. Park, and G. S. Selwyn, Phys. Plasmas, vol. 6, no. 5, pp. 2284-2289, 1999.
T. C. Montie, K. Kelly-Wintenberg, and J. R. Roth, IEEE Trans. Plasma Science, vol. 28, no. 1, pp. 41-50, 2000.
M. Moisan, J. Barbeau, S. Moreau, J. Pelletier, M. Tabrizian, and L'H. Yahia, International Journal of Pharmaceutics, vol.226, pp. 1-21, 2001.

Text: Michael Kong, Loughborough University, UK; Mounir Laroussi, Old Dominion University, USA. Editors: Paul Rivenberg, Gerald Rogoff
Images: St. Petersburg Times; M. Laroussi, Old Dominion University; Plasmion Corporation. Used with permission.