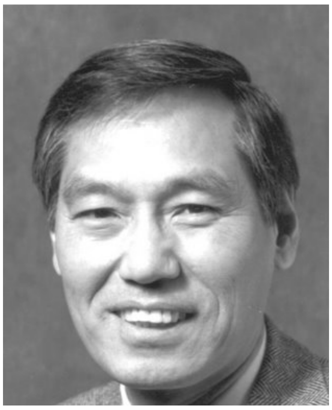

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DARPA's RadioBio and Recent US Bioelectromagnetic Research Programs

The U.S. Defense Advanced Research Projects Agency (DARPA) issued a request for proposals (RFP) in the spring of 2017 by announcing its new research initiative: Radiobio – What role does electromagnetic signaling have in biological systems? [1, 2] The stated goal of this project was to "determine if purposeful signaling via electromagnetic waves between biological systems exists, and, if it does, determine what information is being transferred."

While it is not obvious how many proposals were received, indications are that by the end of 2017, several classified and unclassified projects were awarded DARPA grants under the RadioBio program. The RFP called for clearly identified, hypothesized communication channel(s) with specific predictions and experimental tests that would be undertaken to definitively prove each hypothesis.

The goal of Radiobio is at once innovative and intriguing, especially given DARPA's well-earned reputation of creating breakthrough technologies for national security and beyond. The well-known Internet project is an obvious case in point.

To ascertain, study, and comprehend the roles electromagnetic fields and waves possibly play in the intricate biology of living cellular organisms are of not only fundamental scientific importance, they also conjure up practical and technological values. The possibilities and potential applications in data transfer, information delivery, and communication for command and control are enormous, once the bioelectromagnetic mechanisms for weak cell-to-cell signaling and communication in living organisms are harnessed.

The challenge of RadioBio is simple and complex at the same time.

It is simple, because living biological cells have long been documented to emit electromagnetic fields and waves. Their signals are detectable non-invasively, near the cell, or at a close distance via suitable sensors and instrumentation.

It is largely known that macroscopically, organized cells are capable of generating and emitting detectable electromagnetic signals in the noisy, cluttered environment of living bodies. Indeed, they have been routinely, non-invasively, and successfully applied to assist medical diagnoses and, for some, in therapeutic interventions. The abundant examples include electrocardiography (ECG) and magnetocardiolography (MCG) from the heart, electroencephalography (EEG) and magnetoencephalography (MEG) from the brain, electromyography (EMG) from neuromuscular tissues, and electroretinography (ERG) from the eye, to name a few. These signals, relied upon in modern medical practices, are enabled by the electromagnetic fields and waves emitted by living cells, tissues, or organs. They are detectable from the surface of the human body using specific sensors and electronic instrumentation.

In cardiology, minimally invasive endocardioelectrophysiology of the myocardium is also often performed to help assess sources of cardiac arrhythmias inside the heart. Moreover, in many biomedical research laboratories, miniature penetrating and patch-clamp microelectrodes are regularly employed to record currents from the efflux and influx of biochemical ions, both intracellularly and extracellularly [3].

However, the spectra of the recordings mentioned above are typically low, well below 1 kHz: definitely not in the radio-frequency (RF) region above 3 kHz, the RF band commonly used for wireless communications. These types of low-frequency signals are capable of only supporting very limited information content for wireless-communication purposes.

This is not to imply that they are incapable of transmitting meaningful or purposeful messages using low-frequency signals that are well below the frequency bands commonly used for wireless communication. In fact, even a low-frequency signal with only one bit of information may convey a meaningful message in a purposefully designed wireless-communication system under specialized circumstances, for special purposes or operational requirements.

The complexity arises not merely from the fact that direct measurements of electromagnetic radiation of kHz to THz signals from a single cell or cluster of living cells close-in or far away have yet to be reported. There is a total lack of knowledge of any communication-relevant electromagnetic channel between biological cells or systems, or what biologically significant information may be transferred intracellularly or extracellularly.

Properties and behaviors of ion channels located at cell membranes are basic subjects presented in textbooks on physiology. They describe the critical roles ion channels play in regulating the life process of living biological cells, and by extension, in the functioning of higher organs and structures. Some explicit examples include the voltage-gated ion channels with their exquisite sensitivity to the trans-membrane potential difference [4], and the mechanically gated ion channels with their unique sensitivity to mechanical deformations, stretches, and movements of the cells [5]. The phenomena of biochemical ionic exchanges through channels at cell membranes, ligands, or neurotransmitters through synaptic junctions in neural cells, in particular, are thus well established.

Exchange of biochemical ions via channels for cell membranes, ligands, or neurotransmitters at synaptic junctions represent movements of electronic charge-carrying ions (or charge flow). The flow of electrons forms what is referred to as electric currents. The flow of electrons (electric current) generates electromagnetic radiation by what is known as Ampere's law (a constitutive part of the classic Maxwell's theory of electromagnetism) [6]. The emitted and received electromagnetic waves may embed or encode information or signaling for cell-to-cell communication. They may play a role in intracellular and/or extracellular communication under normal or physiologically stressed conditions. These electromagnetic fields and waves should be amenable to noninvasive detection. The detected electromagnetic fields and waves would thus be obviously purposeful, and they might also be playing some essential roles in signaling and communication alongside biochemical ions.

One project could be to design and execute controlled laboratory cell-biology experiments using isolated cells and cell clusters in culture: for example, isolated, identifiable, and viable snail esophageal neurons and neuron pairs. The snail neuronal cell preparation is selected for enhanced repeatability of results and its ability to maintain cell viability over an extended period of time at room temperature [7, 8]. These experiments could be followed up with other single cells and cell clusters in culture. The cells in culture potentially may transmit and receive signals via electromagnetic fields and waves.

Of course, it would be important to conduct computational bioelectromagnetic modeling to assess electronic signaling behaviors of as many intracellular and extracellular components as practical. The aim would be to specify unique features, signal levels, and bandwidths from ionic current flow and concomitant electromagnetic radiation. The aim would be to define electromagnetic effects that are purposeful, as opposed to just a side effect of ionic exchanges.

The working hypothesis could be characterization of a kHz to MHz communication channel derived from acquired data and preciously known facts, such astime constants from microelectrode-recorded electrophysiological signals and their fading behavior. Development of sensitivity-enhanced passive microsensors, nanoscale biosensors, graphene antennas, and instrumentation with proper bandwidth and sensitivity to noninvasively detect anticipated weak fields in extracellular space.

Actually, announcement of the RadioBio program is a big deal for the bioelectromagnetics discipline. Among other subjects in biology, engineering, and medicine, bioelectromagnetics research explores the effects of electric, magnetic, and electromagnetic fields and waves on living things. The discipline embraces a broad range of topics, the central theme of which falls within the interaction and application of electromagnetic fields and waves in biological systems including plants, seeds, mammalian cells, isolated tissues and organs in animals and humans, over a wide frequency range, which spans static fields to terahertz waves.

For the better part of a quarter century, the number of cellular devices and the variety of uses of wireless electromagnetic fields – including RF and microwaves for security, well-being, medical, and real-world applications, literally, in every aspect of modern life –has grown exponentially. In contrast, funding for bioelectromagnetics research has steadily decreased to a trickle, whether by the government or the public sector. The wireless and cellular telecommunications industry has become complacent, and has had nearly free reign to develop and deploy cellular mobile phones and wireless RF devices and services as they see fit, with little regard for the biological effects and health implications of RF/microwave exposure and the considerable amount of unnecessary RF/microwave radiation to which people are being exposed all day long. The US government seems to have all but abandoned the Radiation Control for Health and Safety Act of 1968 and the preceding deliberations that led to the establishment of the Act [9].

However, there is an exception. The US Federal Food and Drug Administration (FDA) should be applauded for having initiated, and the National Institutes of Environments Health Sciences (NIEHS) and the National Toxicology Program (NTP) praised, for having sponsored and conducted the recently completed US$25M+ research on cell-phone RF radiation and cancer-causing studies in laboratory rodents [10-13].

Among the handful of bioelectromagnetics research projects, another visible and important role the US government has taken up in recent years is the Multidisciplinary University Research Initiative (MURI) grant program of the US Air Force Office of Scientific Research (AFOSR). This ongoing program supports fundamental, cutting-edge research that crosses traditional science and engineering boundaries. Its focus is on in-depth mechanistic research of the interaction of nanosecond pulsed electric fields (nsPEF) with living organisms, and the development of targeted stimulation procedures and processes [14].

The importance of the US government's role in sponsoring and conducting such research programs can not and should not be overlooked in this vital area of science, human health, and safety research investigations. The alternative may be to leave the matter entirely to the cell-phone industry (or perhaps, the military-industry complex) with free reign for RF biological effects research. That would be a scary scenario, since we are being continually exposed to more and more varieties of RF and microwave radiation 24 hours per day, seven days per week, and 52 weeks per year.

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