THE "STORY" OF NONIONIZING RADIATION RESEARCH*

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In the past 18 months a good deal has happened to put this subject in the public eye. Right after the 1977 meeting of the International Scientific Radio Union (URSI) in Virginia on this subject, *The New Yorker* published a two-part article by Paul Brodeur on the dangers of microwaves. He took the view that our military-industrial establishment was keeping the truth from the American public. He went on to enlarge on this theme in a book with a title that reflected his sober and evenhanded approach to the problem: *The Zapping of America: Microwaves, Their Deadly Risk, and the Cover-up*.

Let me note that one ought not charge authors with inventing their own book titles—that might well be the work of their publisher's promotion department. The author may be the most reticent person in the world, but reticence does not sell books, and publishers are not in the book business for their health. Nor are authors always good judges of what is a catchy title, as I once found out to my own sorrow. In 1964 I persuaded McGraw-Hill to call a graduate text I had written with Marvin Chodorow *The Fundamentals of Microwave Electronics*. Ten years later it went out of print after selling a good 2,500 copies and my co-author's daughter, the sociologist Nancy Chodorow, said to us: "You really ought to write a sequel, with a catchier title; how about *The Son of Microwave Electronics?*"

At any rate, it fell to Don Justesen and me to review Mr. Brodeur's book in the May 1978 *IEEE Spectrum*, which is to electrical engineers what the *Journal of the American Medical Association* is to physicians—much like *The New Yorker*, but without the serious parts.

It was not a rave review. We took issue with the author on several

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points, mainly because he tended to highlight certain findings at the expense of some others. That is surely legitimate if one means to persuade, although it might not be the way to add to one's reputation for objectivity. But then, if *we* are to be objective, we must allow that such writings have their uses. Who knows whether the New York Academy of Medicine would have selected nonionizing radiation for its symposium topic this spring if it had not been for the publicity given to Mr. Brodeur's book—to which I have just added, you might have been at home, chuckling over your copy of the *J.A.M.A.*, instead of sitting here listening to some professor with a funny accent.

Now as to the history of our subject—where did it begin? For most professionals of my generation, it began in World War II, when the mass use of radio and radar first led to the realization that we had a new type of potential hazard on our hands that could affect large numbers of young men. I stress young men because such equipment was used and maintained mostly by young men. I was a radar technician myself in my early 20s, in the Eighth Air Force, and I recall the stories that circulated: a radar beam would keep you warm on a cold day, which actually worked; and a short ventral exposure just before a furlough would keep you from inadvertently increasing the local population, which didn't work nearly so well.

Radar might even be dangerous. Disconnect the antenna from an operating radar and hold a piece of steel wool in front of the waveguide connector, and it would start to glow and then to burn in a most spectacular fashion. It was common knowledge that one should not go looking up the waveguide to see whether the transmitter is on; at least use a mirror.

Since young men would continue to service and to operate such equipment after the war, a problem arose for the military services, and later for civilian communications agencies as well, a personnel problem, a morale problem: the young men *would* worry about producing offspring, this time deliberately. I am convinced that it was in part this worry that led our Department of Defense to mount the Tri-Service program in the mid-1950s.[1] No one had seen any steel wool burn or felt more than a minimal heating at microwave power densities below 100 $mW/cm.^2$ The maximum permissible power density was put at one-tenth of that value, and a program was launched at a number of universities to validate that 10 $mW/cm.^2$ limit and to find out—what? I am not for directed research, but that program was not even coordinated; it was everyone for himself. In one of my own experiments I went back to that ventral exposure of young males,

only I used mice. I did not think I would find human volunteers, especially in Berkeley.

We irradiated hundreds of mice with 3 cm. microwaves, right up to the LD_{50}, or lethal dose 50—that is, the power density at which half the mice would die of heat stress—and then we bred the other half, the survivors.[2] Every one of them sired a litter, which led me to formulate the principle that so many G.I.s in all innocence had attempted to demonstrate empirically: that whole-body irradiation by microwaves will kill you before it makes you sterile.

Don Justesen here has recently looked at another result from that series of experiments: that for chronic irradiation below the LD_{50} (but above the maximum permissible standard of 10 mW/cm.^{2}), irradiated mice had slightly *greater* longevity than the controls.[3] Stated most simply, Justesen has confirmed my startling finding of 15 years ago that actually, below a certain level, microwaves are good for you. For one thing, a slight artificially induced fever might help the organism to withstand certain infections.

The Tri-Service program petered out in the mid-1960s, and there was a hiatus in sponsored research in this field that did not end until the early 1970s, after several new developments. Litton Industries and Raytheon learned how to make cheap magnetrons and magnetron power supplies, which are the hearts of microwave ovens. That pushed the price of such ovens below $395. In those days no household appliance, from freezer to color TV, could find a mass market if its price was $400 or more. (Today, that is the price of a pair of fairly good hi-fi speakers.) That brought the HEW's Bureau of Radiological Health into the act. Presently there was a whole new act: the Radiation Control for Health and Safety Act of 1968.[4]

Moreover, government and university scientists gradually became aware that a rather formidable body of literature had been accumulating in the Soviet Union and the countries allied with it. The Bureau of Radiological Health sponsored a meeting at Richmond, Va., in 1969,[5] at which Karel Marha from Czechoslovakia spoke of this work. I helped translate the book he had just written with Jan Musil and Hana Tuhá, and saw it through its American publication.[6] And then another part of our defense establishment started to take an interest in microwave bioeffects. The Tri-Service program had been concerned mainly with health hazards. Its ultimate aim was to find out how big a fence one had to put around a radar transmitter, that sort of thing—but now the military intelligence people

also got busy. They had noticed article after article in the Soviet literature about the effects of exposures much lower than 10 mW/cm.^{2}—not heating now but mostly behavioral observations—and at about the same time they found out that microwaves, at these low levels, were being beamed at the American embassy in Moscow. And not a steady signal, either, but modulated in strange and mysterious ways. What did it all mean? A secret project was created to investigate the Temporarily Unidentified Moscow Signal, which our intelligence community found so hard to digest; that is doubtless why they called it by a name whose acronym is TUMS.

One reason this project was secret had to do with the diplomatic perceptions of the day. Our diplomats were dealing with their Soviet counterparts on a broad front, seeking détente. To introduce a highly controversial issue of relatively minor importance might open a whole Pandora's box of new problems and complications. These perceptions had the inevitable consequence that the entire investigation was dubbed Project Pandora.[7] The makers of our national policy may not have always succeeded in winning the world's hearts and minds, but at least we could rest secure in the knowledge that they had had a classical education.

Nothing much ever came of this project. To this day, who knows what evil lurked in the Russian mind when the Kremlin decided to irradiate our embassy? Perhaps they just wanted to make us nervous; if so, they certainly succeeded. But this episode—that, and possible leaks from the new microwave ovens—had the salutary effect of rekindling government interest in sponsoring more research, and who am I to argue with that? To be sure, much of the research sponsorship was at first aimed at very specific problems. It is only quite recently that some of this new largesse has trickled down to basic research, and you will hear about some of the directions these new fundamental investigations are taking at this symposium. We have even started some collaborative projects with our Soviet colleagues, after meeting with them at a Bureau of Radiological Health-sponsored conference in Warsaw[8] in 1973 and at URSI meetings since then.

Much credit for diverting this renewed government interest from the esoteric and absurd into useful and significant channels belongs to the selfless and persistent efforts of a relatively small number of people who serve, entirely without compensation, on a few influential committees. They are the organizers of professional meetings such as this one. They are the unsung heroes who sit through endless sessions of standards groups

such as those of the American National Standards Institute and the National Council on Radiation Protection and Measurements. Above all, in this field there is the Electromagnetic Radiation Management Advisory Council (ERMAC), which is attached to the National Telecommunications and Information Administration (NTIA). ERMAC's influence actually extends well beyond the government unit to which NTIA belongs, which is the Department of Commerce. Over the years ERMAC has shown that it has no ax of its own to grind. The reviews of current research that are a part of ERMAC's public hearings are well attended and generally respected. As a result, the committee has been able to influence decisions about research funding in departments whose budgets are many times that of the Department of Commerce, such as Defense and Health, Education, and Welfare. If present-day research funding in this field amounts to several million dollars a year, and if a good portion of it is earmarked for fundamental studies, the credit must go in large degree to ERMAC. Working quietly behind the scenes, buttonholing agency heads, cajoling program directors, ERMAC has seen to it that good work goes on and receives at least *some* government support—and I don't say so merely because I sit on the Council myself.

That brings us from World War II to the present. But is that as far back as it goes? Actually, the effects of radiofrequency heating were known before the turn of the century. The big name was Jacques Arsène d'Arsonval (1851-1940), who was a pupil of the great physiologist Claude Bernard (1813-1878), and ultimately succeeded him as professor of medicine at the Collège de France.

But D'Arsonval was not only a physiologist. He had a professional interest in electrical engineering. For many years he served as the editor of a trade journal, *La Lumière électrique*. Today we would call him a bioengineer. He invented the D'Arsonval galvanometer, which remains one of the most sensitive electromechanical current meters to this day. He was one of the first to use a telephone receiver to measure electrophysiological activity in muscles and nerves. And he measured the effects of low-frequency sinusoidal currents on muscles, after first devising a method of checking just how sinusoidal the currents were. He found that at the lowest frequencies there were no contractions or pain, but oxygen absorption and production of carbon dioxide increased in the tissues. At about 10 cycles there were individual muscular contractions, two for every cycle, and then around 25 cycles the contractions fused and the muscle was

contracted all the time, or, as it was then called, tetanized. The intensity of this excitation increased with the frequency, peaked at about 2,500 cycles per second, and then decreased until it was hardly noticeable at the highest frequency his machine could achieve, about 10 kilocycles.[9]

I say kilocycles rather then kilohertz because the name of Hertz was by no means well established then. In fact, these experiments were done at about the same time that Heinrich Hertz (1857-1894) did his famous experiments demonstrating the existence of electromagnetic waves, in 1887 and 1888, just over 90 years ago. Now few people realize that Hertz's experiments were done at microwave frequencies, and all sorts of experiments in what we would call microwave optics were performed with them. Not until radiotelegraphy started a few years later did it become necessary to go to longer wavelengths for communications purposes. But there was no reason to do so in laboratory experiments.

D'Arsonval realized that he had a marvelous new tool in the Hertzian waves right away, from 10,000 cycles to 1 billion—five orders of magnitude in one jump! Within three years, in 1891, he was able to report that he could get *no* physiological effect at all at these frequencies. And in 1892 he sent a paper about it to your sister institution, the French Académie de Médécine,[10] which the Academy regarded so skeptically that they nearly did not publish it. At any rate, he never sent them another paper as long as he lived, and he lived for another half century.

At about the same time, the Serbian-born inventor Nikola Tesla (1856-1943) was making similar experiments in America. He showed that oscillations around 20 kHz. could not be perceived by the human body even at power levels that would make a nearby 4-foot glow tube light up; but a metal object became heated under the influence of a high-frequency field. Incidentally, it is well known that the health of many of the pioneers of radioactivity and other ionizing sources was affected by their experiments and some of their lives were shortened, so it is worth noting that D'Arsonval, Tesla, and another radiofrequency pioneer whom I shall mention presently, Eli Thomson (1853-1937), all lived well into their 80s.

In December 1891 Tesla published an article in *The Electrical Engineer* entitled "Massage with Currents of High Frequency," in which he noted that a person connected to a source of high-frequency currents did experience heating, although he could not say whether it would be beneficial. He referred to the subject again three months later in lectures in London and Paris but on none of these occasions did he describe any actual exper-

iments in that direction. In the 19th century electrotherapy was very popular with physicians, and Tesla's lectures excited lots of interest on both sides of the Atlantic. Dawson Turner in Britain published a simple circuit by which high-frequency fields for therapy could be produced. This circuit was probably due to Eli Thomson, who had gone with Tesla on his tour of Britain; at any rate, the circuit that appears in the next edition of Turner's *Manual of Practical Medical Electricity* of 1897 is ascribed to Thomson.[11] But after this early effort of 1891 and 1892 Tesla dropped the subject, except for a paper he gave before a meeting of the American Electrotherapeutic Association in 1898—there was an entire professional society devoted to electrotherapeutics—and there he did describe some experiments, performed on himself; but, as I say, he lived to be 87. He said the physiological effect depended on voltage, current, and wave shape, and that he had experienced not only heat but also changes in perspiration and blood circulation, and fatigue bordering on somnolescence.

Now D'Arsonval had doubtless heard Tesla's lecture in Paris. He devised a better oscillator, which came to be widely used for medical purposes. In a paper in 1893 D'Arsonval summarized his results: no action on sensibility or contractility; analgesia at the point of application of the electrodes; vascular dilatation and a drop in blood pressure; and increased metabolic rate without a rise of the central temperature but with a greater dispersal of heat at the periphery.[12]

So far, everything had been done by conduction, with the subject connected to the equipment directly. Now—still in 1893—D'Arsonval moved to induction, or what he called autoconduction. He placed an experimental animal inside the coil, and later on a human subject. The person was completely enclosed in a large, man-sized solenoid coil, with big gaps between the turns, like a cage. High-frequency current was passed through it. The person felt neither pain nor any other sensation, but if he held a lamp in his hands it became incandescent. You can see one of these cages at the Wellcome Museum in London and another at the remarkable Bakken Museum of Electricity in Life in Minneapolis. There they have a version that lifts up over one's head and down again like a bell jar. I have stood inside it, and found it to be scary.

D'Arsonval received a lot of help from Paul Oudin (1851-1923), who collaborated with him on the clinical applications of high-frequency currents. In 1892 Oudin found that a resonant coupled circuit worked espe-

cially well. That circuit, the Oudin resonator, was to play an important part in the development of radiotelegraphy in France. Oudin concentrated on the clinical application of a sort of high-voltage brush discharge, which he called the "shower of sparks," to certain dermatological conditions: eczema, acne, lupus, and various gynecological conditions. He also studied the anesthetic effect of small sparks falling on a painful part for some minutes. He found that it gave relief in neuralgia, sciatica, lumbago, and several muscular conditions. He even demonstrated, with the help of a dentist, that teeth could be extracted without pain; and he introduced the use of high-voltage, high-frequency currents in surgery, initially for the destruction of small superficial tumors.[13]

During 1894 and 1895 D'Arsonval conducted a clinical assessment. Seventy-five patients suffering from various ailments were treated. Each was placed in the solenoid for 15-20 minutes daily; in all, nearly 2,500 treatments were given. Most types of hysteria and certain forms of local neuralgia received absolutely no benefit, but for arthritic, rheumatic, and gouty conditions there was a very marked amelioration. An improvement in general health—better sleep, appetite, and energy, and an allayment of nervous symptoms—was followed by an improvement in local conditions, such as movement of a joint without pain. Examination of the urine showed improved metabolism. In three diabetics, sugar in the urine was greatly reduced.

The next step was a series of hospital trials. D'Arsonval had to transport batteries to the hospital as a prime source; these trials were made so early in the development of electrical engineering that his hospital was not yet connected to an electric power supply. He used three methods: electrodes across the thick copper coil, autoconduction by means of the large cage, and something called the condenser couch. That was a large, shaped metal plate on which the patient reclined. The patient formed one of the plates of a condenser, the metal couch itself was the other plate, and the insulating cushions were the dielectric. Other patients were treated by having conduction currents passed through them from the feet to the hands; one end of the thick copper solenoid was connected to a footbath, the other to a bifurcated terminal held in the hands. A current of 350-450 mA was used and treatment was carried out daily for six minutes. How they managed not to kill anyone we shall never know. We do know that of the first three patients, two were treated for diabetes and one for obesity.

After that we have a continuous trickle of journal articles in several

countries that describe the efficacy of high-frequency currents in certain conditions and not in others. D'Arsonval's work was generally acknowledged and his apparatus was used, but from time to time it was suggested that Tesla had a prior claim as the inspirer of medical applications of high-frequency currents. In 1899 the Austrian Moritz Benedikt (1835-1920) considered Tesla's claim to priority, came down strongly in D'Arsonval's favor, and suggested the term D'Arsonvalization in his honor, to denote application of high-frequency currents, in the same way that the terms of galvanization and faradization had been used before.

Meanwhile, D'Arsonval and his assistant Albert Charrin (1857-1907) carried out a series of experiments to determine whether there was any effect on bacteria and various toxins. Cultures were placed in glass tubes within the solenoid. To eliminate thermal effects, the tube containing the culture was surrounded by ice. The results were inconclusive. Tesla continued to claim spectacular results; there was a report that he had found a cure for tuberculosis after he announced that he had killed the bacillus by high-frequency currents.

We can thus see that our subject has a long history. All this work I have been describing started in 1891, and we have not even reached the turn of the century yet. Before there were radar and microwave communications, there was high-frequency diathermy, going back to the 19th century. Good results were obtained in the amelioration of pain from sciatica and other neuralgic conditions. It was noted that there was a general sense of stimulation and increased vigor, probably because of increased circulation. There was some improvement in certain skin conditions, possibly for the same reason. But the basic mechanism was not elucidated, not even the heating.[14] D'Arsonval thought it came about as a result of chemical activity. The idea that high-frequency currents heated by molecular agitation and oscillation was not advanced for a score of years, until Karl Franz Nagelschmidt (1875-1952) published the first textbook on diathermy in 1913.[15]

Meanwhile, diathermy machines also came to be recognized as convenient instruments for electrosurgery. The blade remained cold, and the incision was automatically cauterized and dessicated; that is, the tissue was not burned but dried out—what is called fulguration. The pioneering work was done by one of your colleagues, the New York surgeon George Austin Wyeth (1877-1964), in the 1920s.[16] Another great American surgeon, Harvey Williams Cushing (1869-1939), extended the use of high-

frequency currents to brain operations; and two British surgeons, Dan Mackenzie (1870-1935) and John Andersen (1886-1935), first used the method respectively to extirpate diseased tonsils and for biopsies of suspected malignancies because it killed bacteria and lessened the danger of the spread of cancer cells.

Then, in the 1930s, we had the first attempts to study the effects of short-wave radiation on animals by Joseph William Schereschewsky (1873-1940) in America; and by Erwin Schliephake (1894-19?) in Germany, who wrote a textbook on the medical applications of short waves.[17] It was a big subject in the 1930s. If you look over the program of the Sixth International Conference of Physical Medicine in 1936, you will be astonished to see how much of it was devoted to short-wave therapy. And if you look at a textbook of physical medicine of the day, you will find it raising questions about the selective action of the waves according to frequency, and whether the different dielectric constant of various tissues and organs might make for selective heating.[18] Some of those problems are with us yet. And then there was electropyrexia, or hyperthermia—in short, the induction of artificial fever to fight infection.[19] That was very big in the 1930s, and with it came a return to the methods of D'Arsonval, that is, induction by surrounding coils or condensers rather than conduction via electrodes. That is very big today, too. The effect of ionizing radiation in cancer therapy is known to be enhanced if the body temperature is raised, and that can be conveniently done by simultaneous irradiation with microwaves. One wonders how many of the researchers working on this approach know that heating the whole body in this way is illustrated in the *Archives of Physical Medicine, X-Ray, Radium* for 1932. There is a picture of the patient enclosed in a kind of zipper sleeping bag and placed between two large metal plates. One cannot be sure how much of the heat came from the waves and how much from the zipper bag.

I am told that the National Cancer Institute (NCI) became very enthusiastic about this combined ionizing and nonionizing radiation. In principle, one can direct the microwaves at a specific organ and elevate the temperature locally. The trouble is that if the cancer is localized, there are often other ways of attacking it, notably surgery; so what many of the researchers are actually seeing are metastized cases in which whole-body treatment is indicated. And for elevating the temperature of the whole body, the old zipper bag—or just a plastic garment—works quite well by itself, as NCI now recognizes.

We are now safely arrived at the present. I need not regale you with the current state of the art. It is a function of this symposium to acquaint you with that. I think the points I wanted to make are fairly obvious. First, the history of science and technology is a fascinating subject and of cultural interest in its own right. Certain patterns emerge, for instance, the interplay between technical developments and their applications in medicine or science, and it is by no means a one-way road. D'Arsonval was so far ahead of the technology of his day that he went directly to Hertz's experiments and improved on them, although he was by training a physician and a physiologist; and when the first really powerful French radio transmitter was installed on the Eiffel Tower, it turned out that the radio engineers had to come to D'Arsonval for the most advanced design to be found. And second, it pays to look at what went before. People have been looking for cellular and molecular effects of radiofrequency radiation for decades; there is a long history of side effects to look for, for example, the effects of the production of ozone from electrical discharges in the same room as the patient. Finally, it is a humbling thought that a multimillion-dollar national investment in electronic gear might have been substantially reduced by a timely purchase of a gross of plastic raincoats.

NOTES AND REFERENCES

1. There were four Tri-Service meetings—in Rome, N.Y. (1957, 1958), Berkeley (1959), and New York City (1960)—whose proceedings represented the most advanced knowledge of that day and repay study even today.
2. Prausnitz, S. and Süsskind, C.: Effects of chronic microwave irradiation on mice. *Trans. Inst. Radio Eng. BME-9:*104-08, 1962.
3. Preskorn, S. H., Edwards, W. D., and Justesen, D. R.: Retarded tumor growth and greater longevity in mice after fetal irradiation by 2450-MHZ microwaves. *J. Surg. Oncol. 10:*483, 1978.
4. *Radiation Control for Health and Safety Act of 1968*. Public Law 90-602, 1968.
5. *Biological Effects and Health Implications of Microwave Radiation*. Symposium, Richmond, Va., Washington, D.C., Bureau of Radiological Health, 1970, PB 193-898.
6. Marha, K., Musil J., and Tuhá, H.: *Electromagnetic Fields and the Life Environment*. San Francisco, San Francisco Press, 1971.
7. U.S. Senate: *Radiation Health and Safety*. Hearings before the Committee on Commerce, Science, and Transportation. Washington, D.C., Govt. Print. Off., 1977, Ser. No. 95-49.
8. *Biologic Effects and Health Hazards of Microwave Radiation*. Proc. Intern. Symposium, Warsaw, Poland. Warsaw, Polish Med. Pub., 1974.
9. D'Arsonval, J. A.: Action physiologique des courants alternatifs. *C. R. Soc. Biol. (9)3:*283-86, 1891.
10. D'Arsonval, J. A.: Sur les effets physiologiques comparés des divers procédés d'électrisation. *Bull. Acad. Méd. 27:*424-33, 1892.
11. Turner, D.: *A Manual of Practical Medical Electricity*. London, 1897, 2nd ed., pp. 136-39.
12. D'Arsonval, J. A.: Influence de la fré-

quence sur les effets physiologiques des courants alternatifs. *C. R. Acad. Sci.* *116:*630-33, 1893.
13. Cottenot, P.: Oudin et les courants à haute fréquence. *J. radiol. électrol. Med. Nucl.* *17:*586-88, 1933.
14. Jones, H. L.: *Medical Electricity*. London, Lewis, 1904, pp. 200-04.
15. Nagelschmidt, K. F., *Lehrbuch der Diathermie*. Berlin, Springer, 1913.
16. Wyeth, G. A.: *Surgery of Neoplastic Diseases by Electrothermic Methods*. New York, Hoeber, 1926.
17. Schliephake, E.: *Short-wave Therapy: The Medical Uses of Electrical High Frequencies*. London, Actinic Press, 1935 (German original, 1932.)
18. Krusen, F. H.: *Physical Medicine*. Philadelphia, Saunders, 1941, pp. 382-83.
19. Licht, S., Ed.: *Therapeutic Heat and Cold*. New Haven, Conn., Licht, 1965, 2nd ed., pp. 212-13.