microwave cataracts from all other cataracts, that all microwave cataracts that have been produced in personnel have been detected, or that all inaccurate allegations of microwave cataracts have been disproved. The military services, however, have supported efforts to monitor or detect microwave-induced cataracts in military and industrial personnel [2]. In the climate of such uncertain circumstances, adequate clarification of the subject is difficult to achieve and maintain. Clarification comes in part from experimental studies using animals and in part from the examination of workers who have been exposed accidentally or whose occupational exposure has been for some reason unavoidable. Such a clouded area is subject to unfortunate confusion. Confusion has been created by reports which have alleged microwave injury without substantial proof [3], [4]. Great care should be taken to minimize confusion by avoiding exaggeration. At the same time it is essential not to overlook any possibilities.

Experience gained by painstaking examination of selected populations with proper controls is essential to the elucidation of microwave cataract production in workers beyond the incidence that is normally expected with the passage of time. The determination of a small and subtle effect can only be achieved by the elimination of confusion by the establishment of precise records repeated at appropriate intervals during the lifetime of the worker population. This requires complete examination of the lens and a determination of fully corrected visual acuity. The status of other elements of the eye must be determined to eliminate confusion as to the cause of any present or future alteration in the lens and its relation to any impairment of visual function.

Summary

The production of cataracts by exposure to microwave radiation can occur, although just how it occurs is not well established. Clarification as to the occurrence of cataracts in microwave worker population can only be achieved by careful cumulative records of the visual and ophthalmological status of microwave worker populations.

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by McAfee

Analeptic Effect of Microwave Irradiation on Experimental Animals

During the era of the Tri-Service Conferences [1]–[4], the use of X-band microwave radiation was recommended for the investigation of possible low power density "nonthermal" effects of microwave radiation on the central nervous system. The reasons for this recommendation were that 10 GHz is a widely used radar frequency, and exploratory investigations had shown that this frequency produced alterations in an animal's behavior, especially an analeptic effect; that is, the arousal of a sleeping or anesthetized animal and an increase in the alertness of an awake animal. For example, microwave irradiation to the heads of Nembutal-anesthetized animals aroused these animals from surgically-effective depths of anesthesia. The arousal response invited speculation that certain combinations of frequency, modulation, and power density could modify human performance adversely or favorably and even be of medical interest.

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The observation that the analeptic effect occurred when the head of the experimental animal was irradiated, but not when its abdomen was irradiated, was proposed as evidence for a central nervous system effect when the neurophysiological studies were being planned. It was presumably possible to rule out hyperthermal microwave effects on the deeper neural structures in the brain of an animal such as the reticular formation within the brain stem believed responsible for arousal and wakefulness because the analeptic effect was produced by 10-GHz irradiation, which penetrates skin and bone only very poorly [5]. The lower microwave frequencies incurred the penalty of heating structures within the brain, therefore not allowing one to distinguish between thermal and nonthermal effects. Other advantages could be obtained by using the higher microwave frequencies. The distribution of power in a microwave field is greatly altered by the presence of the animal being irradiated, and the locus of the highest density in a free field at the lower microwave frequencies can be shifted many inches by placing part of an animal, such as the eye of a rabbit, at that locus [6]. The power distribution at the higher microwave frequencies is also distorted by the placement of the animal within the field, but the change observed may be measured in millimeters rather than in inches. At the higher frequencies it is possible to shield all but a small region of the experimental animal from the incident microwave radiation and thus limit the area to be irradiated. To be sure, shielding with aluminum foil and irradiating through a hole of a few centimeters diameter further distorts the field and attenuates the level of power reaching the irradiated tissue. Nevertheless, it was reasoned that since low-level effects were being investigated, further attenuation of the incident radiation was not a problem as long as the analeptic effect could be produced at will. When all these precautions were taken to delimit the site to be irradiated, the analeptic effect continued to be produced although only minute power densities could possibly reach the deeper structures of the central nervous system. The analeptic effect is therefore allegedly a direct nonthermal low power density electromagnetic energy effect that couples the modulated microwave frequencies with special neurons of the central nervous system. This alleged effect can be demonstrated on the rat [7].

X-band microwave radiation was used for the reasons given. Thermistors monitor the rectal temperature of the animal in order to observe any temperature rise that may be produced. To quantitate the power levels used in this experiment was difficult because of the distortion of the microwave field by the presence of the shielded animal and the attenuation of the 10-GHz radiation as it passes through skin and bone. It will have to suffice to state that the radar source was operated at either 300, 600, or 1000 pps at an average power density of 200 mW/cm² [8]. Perhaps 20–40 mW/cm² was actually incident on the animal, an estimate based on measurements taken in its absence. When the head of the rat was irradiated, the animal was soon aroused from anesthesia without a noticeable rise in rectal temperature being observed. The rat would hold its breath as the result of a laryngeal spasm that may then produce asphyxiation, convulsions and death, even after the microwave source was removed. The rat's blood pressure was monitored during the experiment and was observed to be unchanged at first and then to suddenly drop concomitantly with the arousal response. The demonstration of the alleged nonthermal low power density effect was repeated with cats, dogs, and rabbits. In these animals, the skin and bone structure of the head is thicker than in the rat, and the distance through tissue to the arousal center of the brain is greater, but these animals are also aroused at about the same power densities that aroused the rat [7]–[10]. Differences in the responses observed can be attributed to the species used. Rabbits were easily aroused from Nembutal anesthesia, and they vocalized readily. Their blood pressure dropped temporarily. However, unlike rats, rabbits did not asphyxiate themselves. Dogs were less easily aroused than are rabbits. In dogs blood pressure rose and stayed elevated. Cats were relatively difficult to arouse, but their blood pressure was suddenly elevated concomitantly with wide dilation of the pupils, which had been constricted by the Nembutal anesthesia. These effects were immediately reversed (except in rats) if the microwave was removed or if the pulse repetition rate was slowed. The response was reelicited by again radiating the animal.

The preceding observations were not evidence for a low power density effect of modulated microwave radiation, however, because if the lower legs of these animals were also irradiated under the same conditions, a response identical to that obtained by irradiating its head was observed. It was not the central nervous system that was directly stimulated by the microwave radiation as had been supposed. It was the input from the peripheral nerves to the reflex centers of the brain and spinal cord, and to the arousal centers as well, which produced the analeptic response. The skin of the head, face, and lower limbs is richly supplied with afferent peripheral nerve fibers, whereas the skin of the abdomen is not. Injection of the skin of the head or the leg with Xylocaine abolished the response. Peripheral nerve conduction was thus blocked [8]. The arousal phenomenon occurred abruptly following a period of irradiation during which the animal remained quiet and was correlated with temperature rise within the subdermal region of the skin. A thermistor placed under the skin of the lower legs or face of an animal indicated about 45°C when the arousal response occurred [7]–[10]. The temperature within the subdermus reached this value during which time the temperature of underlying and overlying skin remained relatively unchanged. This is because both skin and muscle are well vascularized and are able to dissipate the microwave induced heat. Since the subdermus is poorly vascularized, heat accumulates and temperature rises. Cutaneous nerve branches that lie within the subdermus *en route* from the epidermus to larger nerve trunks deep within the body are thus heated.

The effect of microwave radiation on the peripheral nervous system can be duplicated in all its features by the application of heat from any source to the afferent peripheral cutaneous nerve branches that lie within the subdermus [7]–[10]. Infrared, convective, or conductive heating (from a hollow U-shaped thermode containing circulating water warmed to 45°C) is as effective as is microwave radiation. The analeptic effect may be produced by lower frequencies in the microwave region of the electromagnetic spectrum and has been produced by ourselves at 2450 MHz [7]. The phenomena of the response of the peripheral nerves to the critical temperature of about 45°C is not well known. But it is the neuron and not the terminal end organs of the peripheral nerves that respond to the specific temperature (11). The neural cable is stimulated at any point along its length, from its termination in the skin to its post-ganglionic segment near the spinal cord. The neural signal reaches the spinal cord and produces reflex behavior and then travels to the brain stem to produce the analeptic effect. The set of reflexes and responses observed from thermal stimulation at 45°C of peripheral nerves has also been called a nociceptive response because it is a response to apparently unpleasant stimulation [7]–[11].

It is important to note that for short durations 45°C at the nerve does not cause tissue damage [9]. It is reasonable to conjecture that there may have been many instances, which passed unnoticed by the investigator when subcutaneous temperatures locally reached 45°C in regions that possessed afferent peripheral nerve fibers. Since the experimental animal distorts the microwave field and produces "hot spots" at unintentional locations [6], [12], the determination of the locus of maximum power density before placing some part of the animal at this locus does not assure that the position of the locus remains unchanged.

We have asked ourselves how an inadvertently produced analeptic or nociceptive response might modify the results of an experiment so that the data obtained would be interpreted as the result of some special feature of microwave radiation rather than to its ability to heat tissue. The early investigations of the Tri-Service era yielded an example of the result obtained when these effects are added to the hyperthermal effect of microwave radiation (12). Unanesthetized dogs heated to high core temperatures by means of microwave irradiation behaved in a manner markedly different from dogs whose body temperature was raised to the same degree by convective heat alone. The former animals would often collapse and die if the radiation was not removed. The total heat load of the animals in the two situations was the same and it was at first believed that some nonthermal component of the microwave radiation produced the effect. It was reported that the dogs would occasionally be burned over the rib cage by the microwave radiation and that the superficial evidence of this subcutaneous third degree burn would not make its appearance until many days or weeks later [12]. It was our hypothesis that since burns are occasionally produced, temperatures sufficient to elicit the analeptic (or nociceptive) response were frequently produced and it was the thermal stimulation of afferent peripheral nerves which gave rise to the apparent nonthermal effect [7].

Are other data misinterpreted as the result of some unknown effect of microwave radiation, when hyperthermal effects are not involved? In cats, when peripheral nerves are stimulated by 45°C temperature, adrenal medullary secretion occurs [7] and it is well known that the halogenated anesthetics in combination with adrenalin frequently produce ventricular arrhythmias [13]. In unanesthetized animals the heart rate is modified by an analeptic response if it is accidentally produced [7]. Are experiments on the effect of microwave radiation on heart rate controlled for this possibility? Unanesthetized animals irradiated on feet or face become alert and anxious when the analeptic response is produced [7]. We found that once an animal is subjected to a microwave-induced analeptic response it subsequently attempts to avoid the laboratory situation which leads to this effect. (In one experiment on an unanesthetized human subject, 10-GHz microwave radiation of the wrist produced an analeptic response when the subdermal temperature reached 45°C. Although the experience was not unpleasant or harmful, the subject refused to repeat the experiment [14].) The subsequent behavior of animals that had previously experienced the analeptic effect in an experimental situation is thus modified. These animals are apprehensive and struggle to escape almost as soon as their face is irradiated. The cue for this apparent conditioned response appears to be the previously innocuous warming of the skin by the radiation. Are experiments on animal behavior adequately controlled for the single accidental elicitation of the analeptic effect? It is only good experimental strategy to include controls for the possibility of inadvertent thermal stimulation of afferent peripheral nerves and the production of an analeptic response in awake or anesthetized animals in any experimental situation.

We do not wish to imply that an analeptic response would result from microwave radiation in a nonexperimental situation. Power densities many times in excess of the recommended limits would be required. Even if an individual experienced an analeptic response by accident no harm would be done. Actually the effect might have application to the practice of medicine. An individual who is comatose from drug overdose or cerebral injury might be aroused by treatment with 2450-MHz or 10-GHz microwave radiation applied to the cutaneous nerves of the arm or the branches of the trigeminal or facial nerve until a temperature of 45°C is obtained subdermally. The effect might be a response to the thermal stimulation of the peripheral nervous system, and arousal may be the favorable result.

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