group but of all visual scientists and ophthalmologists, as well as those interested in blindness everywhere.

Every citizen, of course, should be concerned about the present rampaging inflation and its relation to Federal spending. Increasing, too, however, is the cost of blindness and one must reflect if the wealthiest nation in the world can afford to spend less than 0.00000105 of the Federal budget on blinding diseases.

This, however, is not the moment for gloom. The National Eye Institute has been authorized and funded. A youthful, creative, stimulating and discerning director with a background both in clinical and laboratory ophthalmology has been appointed. The Institute has powerful friends in Congress and Drs. Marston, Berliner, and Sherman are anxious that it succeed. A strong Advisory Council is active; its scientific members are knowledgeable about the Federal establishment. Ophthalmology has taken the first step on a journey that promises to open exciting new vistas and ensure that no individual fails to achieve his full potential because of poor vision.

FRANK W. NEWELL

COLOR YOUR CAR FOR SAFETY

The coloring of a motor vehicle, especially the rear-end, can have an important effect upon its visibility. The coloring of a vehicle can also serve other motorists as an aid in judging its size, distance, and relative speed. In studies conducted at UCLA, it was shown that the color of an approaching auto definitely influences a driver's judgment of how far away the vehicle is. Of the colors tested on 164 subjects, blue and yellow made distant objects seem closer in both daytime and nighttime conditions. Gray shades made objects appear farther away.

Traffic Safety reports that the most effective combination for the rear-end of a vehicle would be white or yellow for a background and diagonal stripes of black against this background.

Wheels, chassis, and irregularly shaped underparts may be highlighted by painting such sections aluminum, which gives bright reflections on small areas and improves visibility. ■

BUTANE LIGHTER CAUSES EYE IRRITATION

A case of eye irritation caused by a butane cigarette lighter has been reported in a Letter to the Editor of *The Lancet*. A healthy, middle-aged man complained of blurring of vision in his left eye. After various tests were performed, it was concluded that his blurred vision probably followed a retrobulbar neuritis. However, his symptoms persisted for another 18 months. He was a moderate smoker, and on one occasion, he noticed that when lighting a cigarette he tended to bend his head over his gas cigarette lighter. Occasionally, the butane gas would spray on his eye. He subsequently took greater care when lighting his cigarette, avoiding bending over the lighter, and since then his symptoms have almost disappeared. Correspondent I. Hughes Hallett concludes that it seems possible that the butane may have been sprayed on to the cornea giving rise to slight destruction or perhaps simple edema of the corneal epithelium which then passed off. ■

Glaser

. . . new tools and methods have been created for use in diagnosis and treatment of disease

. . . some of these have harmful as well as beneficial effects

Radiation Effects on the Eye

Walter J. Geeraets, M.D.

Introduction

With the advance of modern science and technology, new tools and methods have been created for use in diagnosis and treatment of diseases. Some of these have harmful as well as beneficial effects. Electromagnetic radiation is within this category of modern achievement and it ranges from wavelengths as short as X rays and gamma (γ) rays, through visible light to microwaves and radio frequencies.

The purpose of this review is to focus on five segments within this wide range of radiation which pose special problems in the health field. Each of these five will be treated separately as follows: (a) Brief background; (b) Uses in medicine, and potential biological hazards, especially as applied to the eye; (c) Radiation levels presently considered harmless.

The five types of radiation chosen for discussion are those most widely used today in a multitude of ways in industry, by the military, in scientific research, in clinical application, and indeed, by the general public.

These five spectral regions are:

1. Ionizing radiation (X rays and γ rays)
2. Ultraviolet radiation (UV)
3. The visible spectrum including the near infrared (IR) region
4. "Far infrared" radiation
5. Microwaves and radio frequencies

However, before these 5 points are discussed in detail, mention should be made of one feature that applies to all of them—radiation protection. It presents a complex problem in all areas of electro-

. . . Unfortunately, effective radiation protection procedures have not been universally adopted

magnetic radiation and requires the cooperation of equipment manufacturers, supervisory personnel, and actual operators of the equipment. Protective measures sometimes must be extended to areas where such equipment is located. Many regulations, standards, and guidelines have been made available through various agencies such as the American Medical Association, the Public Health Service, the National Bureau of Standards (NBS), the International Commission on Radiological Protection and Measurements (ICRP), the National Committee on Radiation Protection and Measurements (NCRP), various installations of the Department of Defense, industrial laboratories, etc. In most instances these agencies have endeavored to provide authentic information and not necessarily material to be used for legislative purposes. However, many state and local authorities have based their protection codes on this information, e.g., NBS handbooks.

Strangely enough, different regulations and controls apply even for similar types of irradiation. For instance, in many states radium and X-ray equipment are under the direct control of the person in charge, who is responsible for the safety of the actual workers, i.e., nursing staff, technicians as well as patients, and of anyone who has access to the radiation area. Radioisotopes, on the other hand, are very rigidly controlled by the Atomic Energy Commission (AEC), and all persons using such materials must be licensed. Many federal, state, and private institutions have their own radiation safety controls, with personnel especially trained in hazard evaluation and elimination. Several states have already enacted radiation protection laws, and the remaining states will undoubtedly follow suit in due time.

Unfortunately, effective radiation protection procedures have not been universally adopted. Even today, many medical and industrial radiation users still receive excessive exposures. Usually this is not due to disregard of authoritative recommendations but to insufficient understanding of the protection problem.

The most effectual aspect in radiation protection remains with the education of workers in the specific fields and environments. The general public, however, unaware and often not knowledgeable concerning these health problems, has to be protected by strict enforcement, either by law or such scientific recommendations which would impose severe legal implications on manufacturers and users as well, if they do not abide by such recommendations.

Whether we are concerned with X or γ rays, UV, visible light, lasers, infrared, or microwaves, an eye-protection and hazard-control program is of prime importance, since the eye is often the most vulnerable organ in the body.

Ionizing Radiation

X rays, discovered accidentally by W. C. Roentgen in 1895 as he was experimenting in his laboratory with an exhausted vacuum tube, literally began a new era in diagnostic and therapeutic medicine and made possible the use of these new radiation properties in many other fields. But it soon became apparent that very severe side effects could be caused by X rays. Reports of skin cancer due to overexposure to X rays appeared within a few years after the discovery. However, little attention was given to these early warnings, and many of the first radiation workers received painful and even fatal injuries. It was soon obvious that prolonged exposure to ionizing radiation could also cause damage to bloodforming organs, malignancies, reduced fertility and life span, and even genetic changes which could affect future generations.

When the Curies discovered radium in 1898, another source of penetrating rays from radioactive materials became available, and within a short time it was learned that these radiations caused much the same tissue damage as X rays. When a radioactive material disintegrates it may give off alpha (α) or beta (β) corpuscular radiation and electromagnetic radiations called called γ rays. Gamma rays and X rays of the same frequency react in the same way. Alpha (α) and beta (β) rays have a much shorter range in tissue than the penetrating X and γ rays, but if materials emitting these rays are deposited inside the body, they can do irreparable harm. This fact was first recognized more than 30 years ago when some radium watch dial painters died as a result of ingesting small amounts of radium-activated luminous materials by pointing their brushes with their lips.

With the development of nuclear energy and the production of radioisotopes, the number of radioactive materials has increased by millions, and the protection problem expanded considerably.

Radiosotopes are, in part, the result of man's ability to make unstable atoms out of stable atoms by bombarding their nuclei with the "atom smashers." By this bombardment the centers of the stable atoms become heavier and out of balance because of the addition of one or more new particles. To return to stability the unstable atoms throw off the extra mass in the form of invisible particles (α and β particles and neutrons) and γ rays. Neutrons are electrically neutral particles which, like γ rays, are extremely penetrating and can travel long distances.

Radioisotopes, however, are not being given major consideration in this paper, although modern radiation centers do employ gamma emitters such as Radium-226, Gold-198, Cobalt-60, Iodine-131, and others, along with orthovoltage and megavoltage X-ray machines, in cancer therapy. Industry and the military also use many of these emitters of penetrating gamma rays. Therefore X and γ radiation may be considered as the same for purposes of this report.

Even in our daily lives ionizing radiation plays a certain role, for example, in the pasteurization or sterilization of food and other products, gauging the thickness of materials and levels of fluids, tracing processes in living and nonliving things, and the production of heat for generating electric power. Everyone is aware of the nuclear powered submarine and surface ships, but not as well known may be the

. . . an eye-protection and hazard-control program is of prime importance, since the eye is often the most vulnerable organ in the body

fact that nuclear batteries have long been used to power unmanned weather stations which automatically record and transmit weather data from the vicinity of the North and South Poles. Radioisotopic devices have been used extensively in the space program and some day may be needed to supply the long-lasting sources of electricity during manned space flight. Already, since time began, man has been exposed to natural or background irradiation from radioactive elements, such as uranium, thorium, radium, and other sources which are everywhere in the earth. Cosmic rays (high-energy particles from outer space) are part of this natural radiation though these tend to be stopped by the earth's atmosphere. The total accumulated dose to age 50 from external radiation including cosmic rays, local gamma emitters, radon in the air, etc. and internal radiation including Potassium-40, Carbon-14, etc. is less than 5 rem (roentgen equivalent man)*.

Today X rays, γ rays, etc., have as wide a range of application as the electromagnetic spectrum itself. They are used to examine and authenticate old paintings reported to be the work of the famous masters and to check concrete structures of modern design for strength and absence of engineering faults. We will find few areas of art, technology, and science where ionizing radiation has not been applied to obtain more perfect results. Industrial and other nonmedical use of radiation, e.g., X-ray installations, present great hazards in their applications for many reasons: (a) some of the X-ray equipment is automatic and operates continuously during working hours, (b) workers may not be biologically oriented nor have been made aware of the effect of radiation on living cells within the body, and (c) the objects being irradiated can vary from a small particle to a giant machine.

The biological system is especially vulnerable to ionizing radiation. In fact, the Atomic Energy Commission (AEC), in Title 10, part 20, of the "Standards for Protection Against Radiation," based its exposure limits on whole-body radiation, exposure to head and trunk, active blood-forming organs, lens of the eye, and the reproductive organs.

The crystalline lens, without blood supply and surrounded only by aqueous and vitreous humors, both, optically transparent media, presents a unique metabolic situation. Therefore, it lends itself to in vivo observations and has served in many experimental studies in research laboratories. Since modern optical instruments allow easy observation of tissue structures and/or changes in the living eye, it is obvious that the lens in the human and experimental animal eye is an a priori model to study biological effects of X rays and other types of radiation in an almost classical environment, i.e., in its natural unaltered setting without experimental artifacts.

There is, however, a great discrepancy in the amounts of doses necessary to produce lens changes in various species. In the rabbit the "cataractous" dose level is 25R (roentgens), in comparison to the "cataractous" dose level of 250–500R required for the human eye. Although the biochemical characteristics of the lens in these two species are not significantly different, precise definition and meticulous care are required in choosing proper "nomenclature" in reference to "cataractous changes." The definition is confined to limits which may be unacceptable for purposes of comparison. To illustrate four classical points, one might state that cataractous changes are: (1) The most minute and subtle changes in the crystalline lens, recognized by the examiner, whether or not they interfere with vision. Admittedly, the term "cataract" for such minute changes is not a very good one and may lead to misinterpretation if not more closely defined. (2) Lens changes which are obvious to any qualified ophthalmologist but which do not severely interfere with visual acuity. (3) Lens changes which reduce visual acuity, but are by no means in the category of mature "cataracts" (though one depends here on the clinical judgment of the examiner in interpreting changes observed in animal eyes and correlating them with possible deterioration of vision in man). (4) Mature cataracts, where the lens is milky white and vision is reduced to light projection only.

As crude as this four-step classification may be, at least it will offer some kind of basis for comparison of effects. While these effects are easily ascertained in animal experimentation, a parallel in human eyes is, of course, not possible because of the absence of well-controlled experimental conditions. Accidental exposures suffered by humans usually lack the exact physical backup, since dosimetry can only be reconstructed from estimates of conditions at the time of exposure.

Even in the exhaustive and elaborate studies of Cogan and Dreisler[1] in 1953 and Merriam and Focht[2] in 1957, we are dealing with the problem of definitions of lenticular changes and related estimates of dose levels reaching the eye at the time of exposure.

In a three-year study of rabbit, monkey, and human lens epithelium in cell culture, comparison of these species-specific cells did not show any behavioral function differences, morphological characterization, mitotic index, etc. The electrophoretic species specificities were still present after the cells were subcultured more than 15 times, though there were some boundary changes in the three species over this period of time. This may lead to the supposition that the X- and γ-ray dose injurious to lens epithelium may be unrelated to the species exposed and that the discrepancies observed could be due to different in vivo observation methods.

However, we cannot exclude the possibility that there may be a true difference in threshold values for lens changes in various species in vivo, even though we cannot confirm this readily in vitro studies. But if there is a true difference, the question is "Why?"—for the metabolism, the topographic location, the physiological properties, etc., of the crystalline lens are probably more similar among different species than are other biological structures. Besides the difference in dose required to produce lens changes in various species, the latent period between time of irradiation exposure and detectable manifestations in vivo can vary enormously. Latency periods of ten and more years have been reported for the human eye, while latencies for biomicro-

... therapeutic effects should be carefully weighed against the damage which could result

* A rem is the quantity of *any* ionizing radiation which has the same biological effectiveness as one roentgen of high penetration X rays.

scopic observable lens changes in rabbit eyes never exceeded one year in our own experiments. One may wonder whether the life span of the individual species has any influence on this rather peculiar phenomenon. This is only a speculation without any scientific basis since metabolic mechanisms in these species and life span (i.e., a factor of about 12), can not be based on a common denominator. Hence any discussions along this line of reasoning is not scientifically acceptable.

More controlled and meticulous studies on human eye exposure using refined dosimetry at the time of radiation exposure are presently under way and hopefully will shed some light on these unanswered questions.

It should, of course, be understood that, faced with malignancies of the head and neck in man, one may feel that risking radiation cataract is justified, since a patient's life could be at stake. In cases where radiation treatment is used for benign ocular conditions, however, the possibility of radiation cataract should certainly be kept in mind and the therapeutic effects should be carefully weighed against the damage which could result.

There are special requirements for shielding radiation workers from age 18 (the earliest legal age for working with radiation), exposed to X-ray emitting equipment. The maximal accumulative dose has been set at 5 rem per year, or 100 mrem per week, based on a 40-hour week (ICRP, 1955). For the general public the recommended dose is 10% of this (NCRP, 1957). Though these data are not generally known to the public and are probably meaningless to them anyway, the public has becomed alarmed about the possibility of dangerous radiation from television receivers. TV receivers may emit some X rays, but the NCRP regulation requires that levels must not exceed 0.5 mrems/hour at 5-cm distance from any outer surface of the instrument. This is a dose well below that which is considered potentially injurious under normal operating conditions.

Ultraviolet and Visible Radiation

Ultraviolet: Although the effects of UV-radiation on eyes and skin have been known for ages, scientific explanations of its interference with biological systems are an achievement of our century. Probably the most accurate information was furnished in 1969 by Pitts and his colleagues.[3] An extensive literature review of electromagnetic radiation prior to the year 1916 was published by Verhoeff, Bell, and Walker.[4]

Effects of UV-radiation on the eye have raised many questions in regard to the typical abiotic effects of specific wave bands within this range of the electromagnetic spectrum. Inadequate intensities of narrow band sources and the lack of physical equipment suitable for accurate dosimetry have prevented correlation of biologic effects and energy levels producing them.

Harmful effects on the eyes primarily involve the cornea by producing a very painful photophthalmia. Objective findings include excessive lacrimation, irritation and congestion of the conjunctivas, punctate staining of the cornea due to epithelial defects, and ciliary spasm. These symptoms usually become apparent after a latency period of from 6 to 12 hours following exposure to UV-radiation. This latency period is variable in both directions and it is related to the degree of exposure. The most common cause is probably negligence, i.e., failure to wear protective goggles when handling industrial welding equipment and when using artificial sunlamps in the home. Excessive exposure to sun reflection at the seashore, in the desert, or from snow fields, will produce the same symptoms. Photochemical denaturation and coagulation of protein structures are the basic mechanisms of cell damage. Nucleoproteins are particularly susceptible with maximal sensitivity at a wavelength of lambda (λ) 2650 Å, while the proteins of cytoplasm are maximally sensitive at λ 2800 Å. The human cornea is highly sensitive at λ 2880 Å. Cogan and Kinsey,[5] who used a high pressure mercury quartz lamp as a source of radiation, presented 0.15×10^6 ergs/cm^2 as the critical value for damages to the rabbit cornea at the wavelength λ 2880 Å. Injuries to the cornea consist mainly of decreased mitosis, nuclear fragmentation, and loosening of the epithelium. In medicine, UV-light is mostly used to sterilize instruments, operating theaters, and intensive care units, where personnel and patients may be exposed to this light continuously or for variable prolonged periods of time.

The American Medical Association[6] recommends that for the primarily used wavelength λ 2537 Å exposures should not exceed 0.5 W/cm^2 for periods of seven hours or less, nor 0.1 W/cm^2 in the case of continuous exposure. The increase of ozone concentration in areas where UV lamps are in use may represent an additional health hazard which must be eliminated by adequate ventilation of such areas. With the realization of space flight, protective devices had to be designed to provide adequate protection for the astronauts primarily against corneal injuries (see page 197). Recent and well-documented investigations conducted by Pitts and colleagues have greatly contributed toward better understanding and more meaningful interpretation of the interaction between this electromagnetic range of the spectrum and biological systems. The complex research conducted by these investigators has furnished fundamental data for the production of photoophthalmia in the rabbit eye. The authors mention 0.054×10^6 ergs/cm^2 as a critical maximum for λ 2700 Å. A value of 0.998×10^6 ergs/cm^2 was indicated for the wavelength range λ 2100–3100 Å, while 0.900×10^6 ergs/cm^2 was given for the wide band of λ 2550–3750 Å. It should be mentioned here that Verhoeff and colleagues cite in their earlier mentioned paper 2.0×10^6 ergs/cm^2 as the critical value for potential damage to the eye, covering the entire UV range.

The corneal absorption data reported by Bachem[7] deserve attention. At first glance these data would appear not to be in agreement with our own findings;[8] in reality, however, this is not the case, when experimental conditions and purpose of the investigations are compared.

In order to protect the eye against overexposure to UV-radiation, conscientious use of protective gear recommended for this purpose should be adequate. More sophisticated measures will be required only in situations as they may develop in the course of future space explorations and more widespread usage of laser techniques.

Visible light: The review by Verhoeff, Bell, and Walker[9] in 1916 is a classical paper on the impact of high intensity light on visual performance. They stated that "no actual artificial illuminant can fairly be considered dangerous from the standpoint of thermic action on the retina"—certainly a most remarkable state-

Harmful effects on the eyes primarily involve the cornea by producing a very painful photo-ophthalmia

ment and absolutely true at the time it was written. As in other fields, however, technical developments have shown that man is not satisfied with facts as they present themselves, but rather will eventually find ways to overcome nature.

The Sun

Injuries to the eyes due to observing eclipses of the sun have been known since earliest history. We find reports of such injuries in works dating back as far as Hippocrates (460–370 BC) and even Plato's Phaedo (427–347 BC) mentions cases of eclipse blindness during his time. Subsequently we find sporadic references throughout the centuries. Higher incidence rates are found during periods when this natural phenomenon occurred more often. Many such occurrences from the years 1911 and 1912 were mentioned by Birch-Hirschfeld, while other authors refer to such injuries within the last decade.

Normally, the intense and bright sunlight causes maximal constriction of the pupil thus, reducing the energy density on the retina. The bright sunlight furthermore, causes painful photophobia which will not permit prolonged direct and fixed observation of the sun. The lid reflex (approximately 150 msec) is another mechanism to protect the eye. The continuous action of these measures would be adequate under normal conditions to avoid burn injuries to the retina.

Some important physical factors are changed when one observes an eclipse of the sun. The retinal image diameter of the sun of about 158 remains the same for the human eye. The pupil diameter however, is usually greater due to the partial obscuration of the sun itself by the moon, and by the use of attenuation filters, thus, decreasing the light intensity entering the eye. However, frequently such filters are inadequate and observation times are greatly extended since there is practically no discomfort while observing this fascinating natural phenomenon.

Energy levels entering the eye at various pupillary diameters have been calculated which may result in temporary or permanent visual impairment. For a pupillary diameter of 3 mm the energy density (or intensity of electromagnetic radiation) entering the eye was calculated to be 5.1 mW/cm^2,* for a 5-mm pupillary diameter this value is 14.1 mW/cm^2, and 36.5 mW/cm^2, respectively for an 8-mm diameter, assuming an irradiance of 71.7 mW/cm^2 at sea level. The second and third values are certainly within a range capable of producing retinal burns even in the presence of lightly pigmented ocular fundi. Corresponding values at an altitude of 100,000 feet (with an irradiance of 107 mW/cm^2) would be 7.6, 21, and 54 mW entering the eye for the three pupillary sizes respectively (A. M. Clarke, personal communication). These calculations clearly indicate the dangers involved in direct observation of a sun eclipse without adequate and scientifically recommended protective devices. Viewing a recording of the event on TV is undoubtedly the safest way to avoid the potential dangers.

* This is a unit of power density used in measuring the amount of power per area of absorbing surface (milliwatt/cm^2).

White Light

Sources of white light have become more powerful and their energy output has increased greatly due to growing demands by various fields such as modern communication systems, wide-screen motion picture projectors, high-speed copy machines, lamps for lighthouse operation, searchlight, photo flashlamps, etc. In spite of the fact that all this equipment has a useful function, there is increasing concern as to potential health hazards, more particularly whether or not prolonged or repeated exposures may have a cumulative effect.

The eye, being a delicate optical system, is highly susceptible to injuries caused by the visible and near infrared range of the spectrum. Light entering the eye from a bright source is focused on the retina and therefore, the thermal irradiance is independent of the inverse square law for image sizes greater than the diffraction limit; a point emphasized first by Buettner and Rose[10] in their paper on ocular hazard from atomic fire balls. Threshold values for energies deriving from "white light" sources, which will cause retinal injury, have been obtained experimentally over many years. Since these values are considered equal, or near equal, to those found after exposure to continuous wave (CW) lasers emitting within the visible spectrum, they are considered in the section on Laser.

Some bright-light sources have found useful application in medicine. Attempts to treat certain types of retinal diseases with light coagulation, in order to avoid complex surgical procedures and to open a way for treating previously untreatable ocular diseases, were made for many decades by using as a light source the sun itself, carbon arcs, army searchlights, etc. All these efforts however, were cumbersome and placed both patient and surgeon under extensive stress.

The Xenon 2001 high-pressure lamp (Osram), manufactured in Germany and designed for use in motion-picture projectors and in lighthouses, finally provided energy sufficient to permit light coagulation of the retina to become a routine therapeutic procedure. Years of experimentation, development, and dedication culminated at last in an instrument which met all the requirements of ophthalmic surgical routine. This pioneering work was done by Meyer-Schwickerath, at that time a young ophthalmologist at Bonn University and Littmann of the Zeiss Optical Company. Subsequently, laser sources have been used quite successfully to treat similar pathological conditions of the eye.

This Xenon high-pressure lamp mentioned above emits rays in the near infrared as well, a feature less desired, since this portion of the spectrum is strongly absorbed by the ocular media. Though these wavelengths can be easily removed by filters, the commercially available instrument has not incorporated this protective means. It should be stated, however, that no ill effects under proper operating conditions have been reported over the last 1½ decades of operation.

Since infrared has been mentioned, a word should be said regarding the effects of chronic exposure to IR-radiation. Glass-blowers and steel-puddlers have been reported to develop cataractous lens changes—hence the term "glassblower cataract." There are two typical changes, i.e., initial posterior cortical opacities and secondly exfoliation of the anterior lens capsule. Since the lens lacks heat dissipating mechanisms, such as circulating

blood, the heat generated by absorption of IR-rays in the adjacent pigment cells of the iris and conducted into the lens, raises the temperature in the lens. Exfoliation of the lens capsule is, therefore, attributed to such prolonged temperature elevation. Many years of exposure to IR-radiation are required, however, to produce such changes in the crystalline lens. The only protection against such injuries would be either complete automation or the use of goggles equipped with IR-absorbing filters. Complete automation is not feasible as yet, but the use of goggles, though inconvenient to the wearer under the already uncomfortable working conditions, is mandatory for steel-puddlers working close to the pots. Glass-blowers usually adhere to this practice.

Laser

One of the magnificent achievements of the past decade is the laser. The idea of stimulated emission was proposed by Albert Einstein in 1917. I. Schawlow and C. D. Townes suggested in 1958 that optical maser action should be possible and Maiman achieved the first working pulsed ruby device in 1959 in this country, while parallel work proceeded in Russia. Townes, in the United States and V. N. Prokhorov and A. N. Basov in the U.S.S.R. were rewarded for their accomplishments with the Nobel Prize in physics.

The instantaneous power levels available were so high as to give rise to speculation of many unique effects, and sparked the conversation at many scientific meetings for some time. The mechanism of

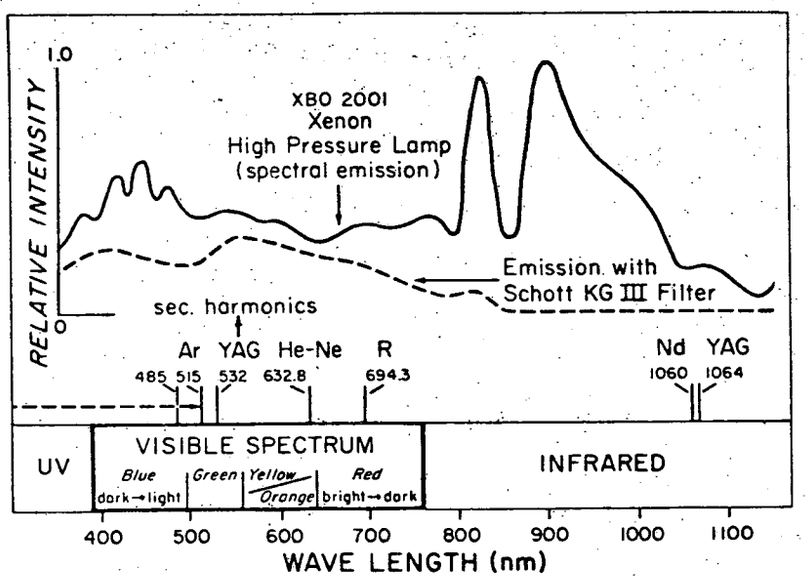

Figure 1. Spectral position of light emitted from various laser sources in comparison with emission characteristics of a Xenon high-pressure light source.

. . . calculations clearly indicate the dangers involved in direct observation of a sun eclipse without adequate and scientifically recommended protective devices

energy generation results in an emission of exceptionally uniform wavelengths, with a bandwidth of infinitesimal size—a fraction of an angstrom unit. Various materials have been found which through proper choice allow one to achieve stimulated emission at distinct wavelengths throughout the visible, near-UV, and far-IR spectrum. Output ranges from single pulses as short as 10^{-12} second to continuous. Practical utilization for the laser has been found in the areas of surveying, micro-machining and welding, communications, and three-dimensional direct imaging or holography among others. A recent use of laser in space was the well publicized lunar experiment in the Apollo series. See Figure 1.

But here also, due to the enormous variety of energy levels, wavelengths, exposure times, etc., safety criteria policies and laws designed to cope with these problems have assumed an important role and controversies have arisen as to finding ways toward the safe handling of this new invention. Excessively rigid application of such measures or restrictions of practical use of these new sources of electromagnetic radiation may severely limit the tremendous potential of these sources and their use for further scientific and industrial progress. It will be necessary to protect vast numbers of industrial employees, military personnel, and others, against exposure levels not as yet evaluated in full detail regarding single time exposures, or prolonged exposure at relatively low energy levels.

Although retinal injuries caused by thermal effects due to light absorption by the retinal pigment epithelium may be considered fairly conclusive, photochemical effects, i.e., interaction of light with visual pigments in photoreceptors under those conditions, or in other words, photochemical damage is not fully understood and requires extensive investigation. Nonlinear effects including acoustic transients, shock waves, re-radiation, and second-order absorption caused by extremely high-power levels of giant-pulsed or q-switched lasers are capable of producing severe damage, other than thermal, to biological systems.

Up to now the use of laser beams for therapeutic applications has not reached a significant degree. Some achievements were made in dermatology mainly in treatment of portwine lesions and removal of tattoos. In cancer therapy use of the laser has been unrewarding except in the eradication of certain extensive multiple skin malignancies; however, the success in this area does not as yet surpass that obtained by conventional therapy. In dentistry, prevention or treatment of caries with laser is still in the experimental stage. Ophthalmology is probably today's only medical specialty where laser beams have become a routine therapeutic tool for a variety of eye diseases. The constantly increasing number of wavelengths and increased power output will enable us eventually to select particular spectral regions and exposure times to meet individual requirements. As an

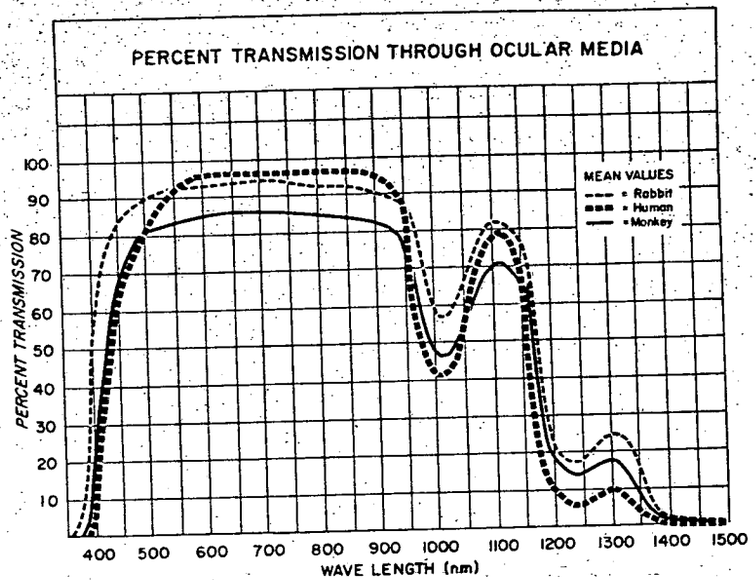

Figure 2. Percent transmission for light of equal intensity through ocular media of human, monkey, and rabbit eyes.

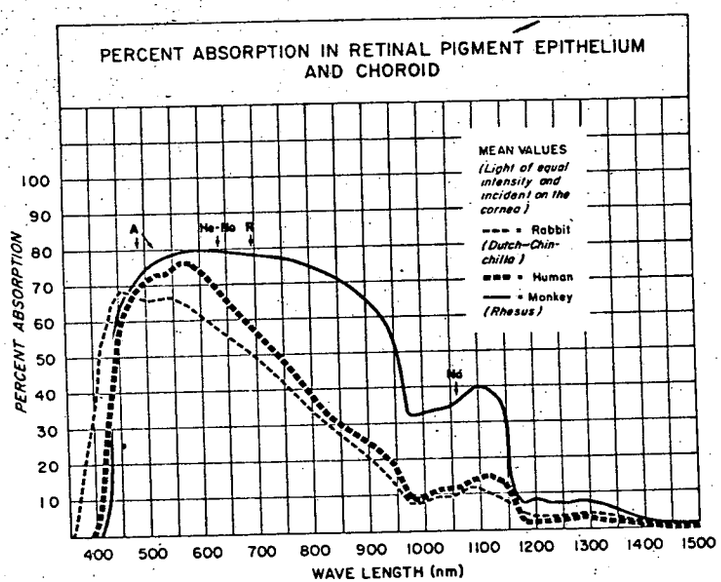

Figure 3. Percent absorption in retina and choroid for light of equal intensity and incident on the cornea of human, monkey, and rabbit eyes.

Ophthalmology is probably today's only medical specialty where laser beams have become a routine therapeutic tool for a variety of eye diseases

example one can list the Argon gas laser which has its principal emission in the green portion of the spectrum. This spectral region is particularly suitable for treatment of vascular lesions of the retina because of the absorption characteristics, and at present is under intense clinical investigation.

Continued research on the use of laser in medicine is of paramount importance else a major breakthrough in diagnostic, preventive or therapeutic medicine may be missed.

It was mentioned earlier, that "white light" threshold values for retinal injury are approximately of the same order of magnitude as those for CW lasers which emit light within the same visible range of the spectrum. This does not pertain to lasers producing light in the near-IR region, e.g. the neodymium (λ 1060.0 nm) or the Nd-Yag (λ 1064.0 nm) lasers because of the marked difference in the spectral properties of the eye in this frequency range.

Due to the characteristics of ocular absorption through the visible region, the light emitted by the ruby laser (λ 694.3 nm) is absorbed by the retinal pigment epithelium 5–10 times more efficiently than the wavelength produced by a neodymium laser (λ 1060.0 nm). These variations are due to greater absorption of the neodymium wavelength by the ocular media and a higher degree of reflection by the retinal pigment epithelium[11] (see Figures 2 and 3).

At present special committees and other agencies concerned with ocular protection consider various maximal permissible exposure levels. The following values, however, are widely used and it is assumed that these data are conservative without being excessively restrictive, at least until more definitive recommendations become available.

Suggested exposure levels are 10^{-4} W/cm² for continuous wave (CW) lasers emitting light within the visible range; 10^{-5} J/cm²* for long pulses (γ sec-msec ranges; 10^{-6} J/cm² for q-switched pulses (nano second ranges) (see Figure 4). Acceptable values for CO_2 laser are mentioned in the discussion of effects of far-IR radiation on the eye.

There are, however, other points to be considered not necessarily due to laser radiation effects, but rather caused by exposure to support systems, e.g., explosive gases, leakage of compressed toxic gases, injuries from electrical shock due to the need for high-voltage power supplies, etc. All of these are potential health hazards and must be properly guarded and shielded to minimize the danger of accidents.

"Far Infrared" Radiation

Radiation effects from this particular range of the spectrum on the eye have

* Unit of energy density for predicting damage potential of a laser beam (Joule/cm²).

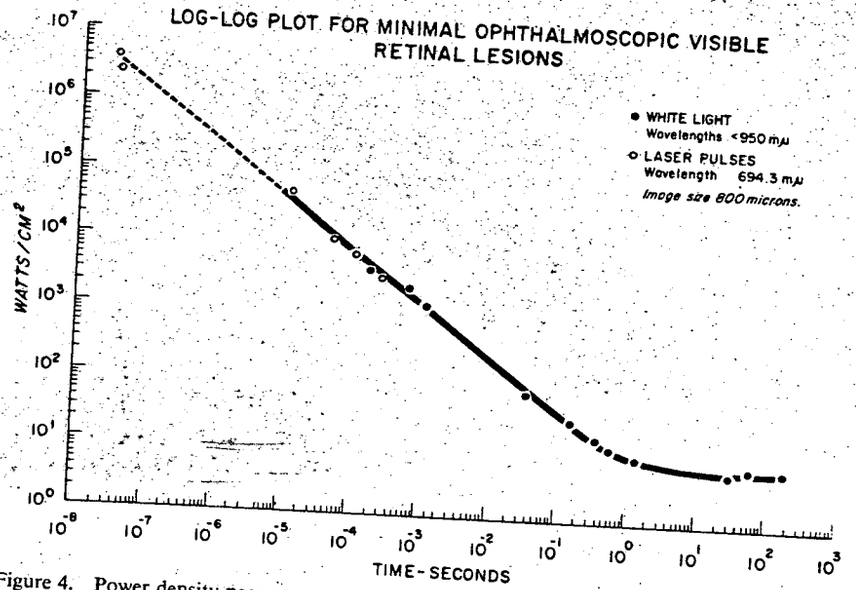

Figure 4. Power density necessary to cause minimal ophthalmoscopically observable lesions.

become a matter of concern since the CO_2-laser was developed. This CW gas laser is capable of reaching exceptionally high power levels—sufficient to melt even firebrick. Since its wavelength (λ 10.6μ) is absorbed by media transparent for wavelengths within the visible range, the cornea is particularly vulnerable. The first 10μ of tissue absorb about 67% of the energy. For relatively low energy levels, requiring extended exposure times to produce injuries, the blink reflex (approximately 150 msec) may be sufficient protection, as the thermal effect on the corneal epithelium would elicit this reflex mechanism. Exposure times shorter than the blink reflex may produce severe corneal damage when high energy levels are involved. Such damage may range from reversible superficial injuries of the epithelium to permanent corneal opacities, corneal ulcers, corneal perforation, and damages of iris and lens, i.e., a possible loss of the eye. The mechanism of this harmful effect is strictly heat-induced denaturation and coagulation of cell proteins caused by absorption of such radiation.

Due to the enormous energies it is capable of producing, this laser has found widespread industrial and military application. For medical use the potentials of this laser became soon apparent in microsurgery, where it served as a precision cutting tool, permitting refinement of techniques and increasing accuracy along with the possibility of "bloodless surgery." Further perfection of this laser has made it a surgical instrument which after many stages of development finally can be recognized as a valuable adjunct in medicine. Its practical use is still being explored. At this time exposure levels below 0.1 mW/cm² are considered safe.

Microwaves

James Clerk Maxwell and Hertz Heinrich Rudolf (1857–1894) are the two most distinguished names connected with electromagnetic radiation in the spectral range of 10^{-2}–10^{6} cm. Their studies during the second half of the 19th century have provided the foundations for modern achievements in the fields of microwave systems, radar, radio, and television networks.

The rapid development and the expansion of industrial and military use of microwave generating equipment, as well as installation of microwave ovens in private homes, restaurants, hospitals, schools, etc., have increased the concern regarding the effect of this particular type of radiation on biological systems. Possible harmful effects on the human body came initially to mind during World War II in connection with exposure of radar personnel. However, only a few cases of overexposure with resulting injuries became known.

Tissue penetration by microwaves is wavelength related and there are variable possible effects on the eye. For instance, surface layers of biological material will absorb microwaves with wavelengths within the millimeter range. At a wavelength of 3 cm a maximal temperature rise occurs in the anterior chamber of the eye close to the cornea, and overexposure may produce injuries. For a 6-cm wavelength we find a maximal rise in temperature in the anterior cortex of the lens, while for a wavelength of 12.5 cm these high temperatures develop in the posterior portion of the lens or in the adjacent vitreous. Initial lens changes are observed in areas with maximal absorption, i.e., where high temperatures exist.

Exposure time and power density, in addition to the wavelength characteristics, are other factors responsible for producing biological damage. Overexposure to microwaves produces in man, in addition to cataracts and iritis, vasculitis, temporary sterility of males, blood changes, and neurological disturbances. In the Russian literature mention is made of behavioral changes with fatigue and nervousness in persons subjected to prolonged microwave exposure; it would appear that these changes could be confirmed in animal studies. On the basis of present knowledge regarding acceptable temperature increases in body tissues, the suggested safety standard in the U.S. is 10 mW/cm² as averaged over any possible 0.1 hour period and a frequency range of 10 megahertz (MHz) to 100 gigahertz (GHz); i.e., power density of 10 mW/cm² for periods of 0.1 hour or more; energy density of 1 mW hr/cm² during any 0.1 hour period.[12] The U.S.S.R. standard[13] is 0.01 mW/cm². Later Russian publications give maximal acceptable power densities of 0.1 mW/cm² for exposure times of up to two hours, and 1.0 mW/cm² for not more than 20 minutes. The United States Standard of 10 mW/cm² was accepted upon recommendations by Schwan and Li[14], who based this recommendation on minimal detectable biological

Overexposure to microwaves produces in man in addition, to cataracts and iritis, vasculitis, temporary sterility of males, blood changes, and neurological disturbances

effects on the eye and testes in animals for a power density of about 100 mW/cm²; hence, a safety factor of 10 was applied for maximum acceptable exposure.

Due to the steadily increasing number of microwave ovens sold in recent years it was recommended that maximal permissible radiation should not exceed 10 mW/cm² at a distance greater than 5 cm from the door seals.[15] The public is forced at present to rely on the diligence of the manufacturers in checking their products for excessive radiation leakage and installation of safety cutoffs preventing operation of the oven unless the doors are properly closed. Dosimetry standardization, particularly with regard to equipment in the field, presents significant physical difficulties. A recent survey, conducted by a group of agencies, showed that 22% of a total of 494 units which were checked, emitted radiation levels in excess of the recommended 10 mW/cm² under normal operating conditions.[16]

Research regarding biological effects is urgently needed to develop adequate protection without unnecessary interference with the future development of the practical uses of this electromagnetic radiation. Biological criteria of this type are difficult to establish due to our lack of knowledge of harmful end points and their definition in relation to the wide range of frequencies. In many fields of animal experimentation, extrapolation of data obtained in such experiments to human conditions poses another problem which should be handled with caution, because of the frequency-related tissue penetration.

REFERENCES

1. Cogan, D. G., and Dreisler, K. K.: Minimal amount of X-ray exposure causing lens opacities in the human eye, *Arch Ophthal* 50:30 (July 1953).
2. Merriam, G. R., and Focht, E. F.: A clinical study of radiation cataracts and the relationship to dose, *Amer J Roentgen* 77:759–85 (May 1957).
3. Pitts, D. G., et al.: The effect of UV radiation on the eye, US Air Force Sch of Aerospace Med Rept SAM–TR–69–10 (AFSC) Brooks AFB, Texas (Feb. 1969).
4. Verhoeff, F., H., Bell, L., and Walker, C. B.: Pathological effects of radiant energy on the eye, *Proc Amer Acad Arts Sci* 51:630 (1916).
5. Cogan, D. G., and Kinsey, V. E.: Ophthalmic ultraviolet action spectra, *Amer J Ophthal* 41:969 (Jan. 1956).
6. American Medical Association Council of Physical Medicine: Acceptance of ultraviolet lamps for disinfecting purposes, *JAMA* 137:1600 (Aug. 1948).
7. Bachem, A.: Ophthalmic ultraviolet action spectra, *Amer J Ophthal* 41:969 (June 1956).
8. Geeraets, W. J., and Berry, E. R.: Ocular spectral characteristics as related to hazards from lasers and other light sources, *Amer J Ophthal* 66:15 (July 1968).
9. See reference 4.
10. Buettner, K., and Rose, H. W.: Eye hazards from an atomic bomb, *Sightsav Rev* 23:194 (Winter 1953).
11. See reference 8.
12. United States of America Standards Institute: Report C95.1 (1966).
13. USSR Ministry of Hygiene: Publication no. 272–58 (1958).
14. Schwan, H. P., and Li, K.: Capacity and conductivity of body tissues at ultrahigh frequencies, *Proc Inst Radio Engrs* 40:1735 (1916).
15. US Dept HEW: Radiation Exposure Rev, Report OCS 69–1 (July 1969).
16. *Ibid.*

NATIONAL VOLUNTARY HEALTH CONFERENCE

The Third National Voluntary Health Conference will be held May 7–8, 1970 in Washington, D. C. at the Statler-Hilton Hotel. This is a national leadership conference to explore the roles, responsibilities, and relationships among professional associations, governmental agencies, and voluntary organizations in the provision of health care. The meeting is sponsored by the AMA's Council on Voluntary Health Agencies.

The prevention of damage to the astronaut's eyes during the Apollo lunar missions was of paramount importance

Visual Requirements and Eye Protection for the Lunar Astronauts

Roger C. Fitch, O.D.

Visual Requirements for Astronauts

The visual requirements for astronauts are basically the same as those necessary for admission to flight training in the United States Air Force. There are now, however, scientist–astronaut positions for which visual requirements are not as rigorous as those for the previous groups. Scientist–astronauts were selected primarily on the basis of their technical knowledge in a scientific field applicable to the NASA mission. For those individuals who must wear a visual correction in order to adequately perform the mission requirements, NASA has awarded a contract to provide spectacles which could be worn within the pressure suit helmet during either lunar extravehicular activity (LEVA) or non-LEVA conditions. These spectacles can be ordered with or without a prescription insert so they could be used also by those astronauts who do not need corrective lenses.

Electromagnetic Radiation

Visible light is one small portion of a large spectrum of electromagnetic radiations (or energy) from the extremely short cosmic and gamma rays to the X rays, ultraviolet, visible, infrared, Hertzian, induction heating waves, and beyond.