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Work Practices

Engineering Controls

Biological Monitoring

Methods of Analysis

Treatment

Transportation/Handling/Storage/Labelling

A preventive role for optometrists in the protection of eye health

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J. G. DAUBS, O.D.

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speeds up to 180 mph, 50 miles range is sufficient. Those with speeds up to 600 mph require a range of 150 miles; and for the supersonic transport (SST), a 300 mile range is needed.

Most present radars have a range of 150 miles, obtained with a peak power output of less than 100kw.

The peak power output of a radar is an important consideration since it indicates the degree of danger and can be used with the pulse width and pulse repetition frequency to calculate the average power output of the radar (average power = peak power X pulse width X pulse repetition frequency). Knowing the average power output and the antenna focusing characteristics, one can determine the power density or energy level produced by the radar set. The maximum safe energy level (MSEL) is generally taken to be 10 milliwatts/cm^2 or 9.29 watts/$ft.^2$ (Ref. 5)

Some organizations recommend a limit

TABLE I

SUMMARY OF RE
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guide which is connected to energized transmitters.

c) Never climb poles, towers or other structures into a region of possible high radar field without verifying that all transmitters have been turned off.

A preventive role for optometrists
in the protection of eye health

Eye hazards of airborne radar

J. G. DAUBS, O.D.

The eye hazards of high-power radar are better known[1] than those of low-power radar.[2] The optometrist can help to prevent eye damage by alerting radar users to this source of potential injury.

One source of eye damaging low-power radar that has become increasingly popular is the airborne weather-avoidance radar used in airline, military and business or general aviation aircraft. Airline and military operators have control over those exposed and have established procedures to prevent eye damage. Protective devices are used, and safe methods for testing and repairing are outlined for maintenance technicians. Flight crew operating procedures are specified to prevent injury. A typical airline policy manual[3] states that radar shall not be turned on when near objects such as buildings, ground equipment or personnel, or within 150 feet of an aircraft being refueled. The manual gives the example of "radar being capable of igniting flash bulbs at less than 25 feet."

Business and general aircraft operators do not always have control over their operating surrounds and in some cases have not been aware of the dangers of these low-power radars, even though the radar manufacturers' operating manuals do warn of this. Questioning operators, maintenance personnel and ground-handling technicians about the hazards of this radar resulted in a variety of responses.[4] Some considered these radiations dangerous, while others thought that the power levels were so low as to be insignificant and that they would be able to feel the heat if the energy level was high enough to constitute a hazard. This general laxity, combined with a congested ground environment, results in a higher probability of exposure. Aircraft used in business and general aviation are typically smaller and have lower ground profiles than airliners, which brings the nose-installed radar antenna down nearer the eye level of ground personnel, thereby increasing the risk of injury.

Airborne radar is considered a necessity by pilots traversing areas of thunderstorm activity. Although ground-base radar is available throughout the U. S. and in most high traffic areas of the world, it is not used for weather avoidance. It is used to aid the ground-base traffic controller in expediting the flow of air traffic. Ground radar units often use special circularly polarized antennas designed to eliminate the weather return from their scopes. Since ground radar controllers direct the flow of traffic but cannot see the weather, it is the responsibility of each pilot to avoid flying into poor weather. Airborne radar is the best tool the pilot has for detecting and avoiding thunderstorms. It provides a method for safe and comfortable flying around storms by the most economical route. This same airborne radar unit can be used for ground mapping to supplement other navigation equipment. Thus, most well equipped business aircraft have radar installed.

The type of radar installed depends on the speed of the aircraft. For aircraft with speeds up to 180 mph, 50 miles range is sufficient. Those with speeds up to 600 mph require a range of 150 miles; and for

the supersonic transport (SST), a 300 mile range is needed.

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TABLE I

SUMMARY OF BELL SYSTEM RECOMMENDATIONS

1. For the time being, microwave exposure limits may be classified as follows:

Average Power Density mw/cm^2	Classification
Above 10	Potentially hazardous
Between 1 & 10	Safe for incidental or occasional exposure
Below 1	Safe for indefinitely prolonged exposure or permanent assignment

2. Employees are cautioned to abide by the following rules:

   a) Never enter an area posted for microwave radiation hazard without verifying that all transmitters have been turned off and will not be turned on again without ample notice.

   b) Never look into an open waveguide which is connected to energized transmitters.

   c) Never climb poles, towers or other structures into a region of possible high radar field without verifying that all transmitters have been turned off.

of 1mw/cm^2 for prolonged exposure. The General Electric Company requires monitoring at a 1mw-mean value in order to make allowances for harmonics and spurious waves. The policy of the Bell Telephone Laboratories is given in Table I.[4]

The MSEL of 10mw/cm^2 is based on the heating effect this average power density would have. The testicles and eyes are most susceptible to these heating effects since they are not in the body heat sink. Mumford[5] has reviewed microwave radiation hazards and described the events that lead to the establishment of 10 mw/cm^2 as the MSEL. He cites examples of microwave produced cataracts in laboratory animals and clinical case reports in humans.

Although some authors are not convinced that microwave induced cataracts do occur in humans, the case reports, beginning with that of Hirsh in 1952[6] up to the most recent this author has seen (1967), that of a 23 year old French radar technician with bilateral cataract and no other etiology,[7] led me to believe that radar energy should be avoided, pending further proof of its safety.

The MSEL is a widely accepted standard, but even it may not necessarily insure safety. Heating effects may not be the only source of ocular damage. Other possible effects not related to increased temperature are chemical changes in the protein molecules resulting from high peak powers at short pulse widths. In other electromagnetic radiations, short pulse widths have caused shock waves in the retina that have exploded the cones. Thus, the MSEL, while useful, may not be the final criterion for microwave radiation safety. The other factors involved become so complex as to make a simple overall standard difficult to define.

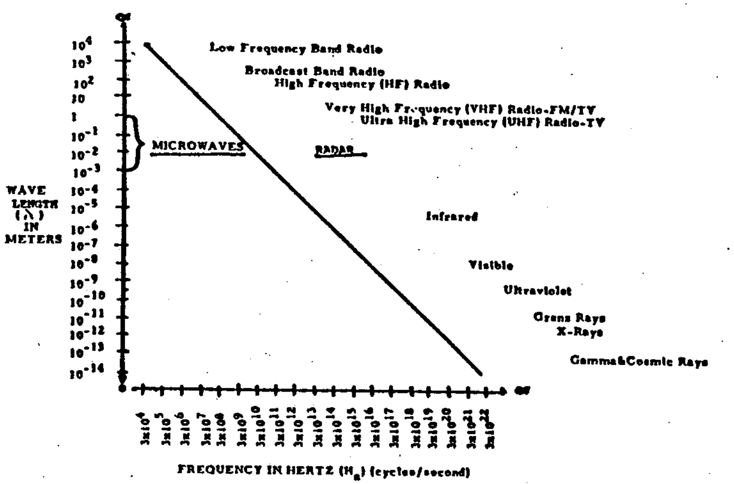

Figure 1. The electromagnetic spectrum showing the relationship of microwaves and radar to other radiations.

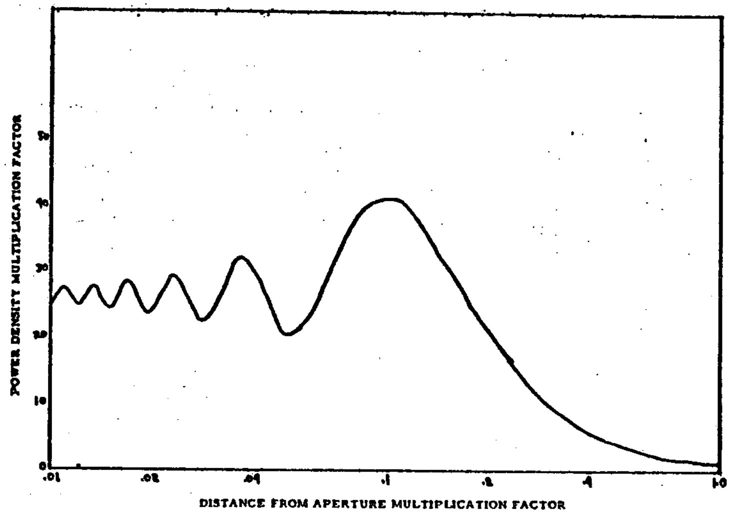

Figure 2. AXIAL POWER DENSITY IN THE NEAR FIELD NORMALIZED TO UNITY AT $2D^2/\lambda$.
Adapted from R. C. Hansen, the Microwave Engineers' Handbook—1964.

While most present-day weather radars have a 150 mile range, the "second generation" radars will have a range of 300 miles under penetration conditions (that is, they would see for 300 miles even through storm clouds and rain). Avoidance range would be 580 miles. The performance requirements for this next generation radar were given by the Airline Electronics Engineering Committee in ARINC Specification 564. This specification did not prescribe the method by which manufacturers should achieve this performance. They could either increase transmitter power output, increase receiver sensitivity, or both. Most likely, both methods will be used. Increased power will increase the eye hazard.

It was anticipated that the "second generation" radar would be introduced with the "second generation" jets, the jumbo jets and the SST. TWA jumped the gun, however, and decided to install these new radars in their future Boeing 707 and 727 aircraft.[8] Other airlines may well follow their lead, as will some business aircraft operators.

Radar equipment radiates electromagnetic energy at a frequency higher (wavelength shorter) than shortwave radio, but at a frequency lower (wavelength longer) than infrared. Figure 1 shows the relative location of radar in the electromagnetic spectrum.

Airborne weather radars operate in either C, X, or K_u bands. C-band (5400 MHz) radars give better information in depth and have penetrating effect. X-band (9375MHz) provides better range but is more attenuated in rain. K_u-band (15,500MHz) is designed for smaller aircraft and has characteristics similar to those of X band.

Radar energy is generated in short bursts or pulses by a magnetron and sent through wave-guide ducts to a parabolic

TABLE II

Radar Type	Freq. (mc) (MHz)	Peak Power (kw)	Ave. Power (W) W_o	Ant. Dia. (")	D_λ	Min. Safe Dist. (ft.) d_m
RCA						
AVQ-10	5400	75	60	34	16	26
AVQ-20	9375	20	16	24	19	16-1/2
AVQ-46	9375	8	7	12	9	5-1/4
AVQ-55	9375	15	12	18	15	11
AVQ-30X	9375	65	65	30	24	42
AVQ-30C	5400	75	75	30	14	27
BENDIX						
RDR-1E	9375	75	67.5	30	24	43
RDR-1F	9375	75	67.5	30	24	43
RDR-100	15,500	10	8	12	16	10
COLLINS						
WP 103G	9375	25	33	18	15	18

Note: For these calculations the highest power available and the largest antenna available were used. In aircraft with smaller antenna installations the minimum safe distance would be less then shown above.

reflector or "dish" from which it is emitted in the shape of a narrow conical beam. The intensity of the beam follows the inverse-square law in general. However, at distances close to the dish $(< 2D^2/\lambda)$ Fresnel diffraction occurs, resulting in peaks and valleys that do not follow the inverse-square law.[9] Figure 2 shows the variations in axial power density in this near-field region. The power density at 1/10 the near-field distance is at a maximum and is over 41 times the density at the near-field distance. The MSEL of 10mw/cm² is reached at this distance in the near-field if the energy level at the near-field distance is only 0.242 mw/cm².

Table II lists some typical airborne radars, showing their characteristics[10] and the calculations of the minimum safe distance, (dm) based on a MSEL of 10 mw/cm², using the following formula[11]:

$$d_\lambda = 0.217 D\lambda \sqrt{W_o}$$

Where:

D_λ = antenna diameter in wavelengths

W_o = average transmitted power in watts

These calculations assume an efficiency of 55% and are for on-axis radiation only and ignore the effects of objects in the near field. Since the actual efficiency will vary, and side lobe densities and the effects of near field objects are difficult to predict, actual field energy densities were measured around typical airliners and business jets. The instrument used was an Electromagnetic Radiation Detector, Model B86B1, manufactured by Sperry Microwave Electronics Company, Division of Sperry Rand Corporation, Clearwater, Florida. This device is sensitive over the frequency range of 400MHz to 10,000MHz. Throughout this band it responds to all planes of polarization: linear, circular, random, pulsed or continuous. It, therefore, measures the total field density. The instrument is a thermistor bridge with an output meter calibrated from ⅛ to 20 mw/cm². Accuracy is given as +2 to −1 db at any frequency within the operating range.

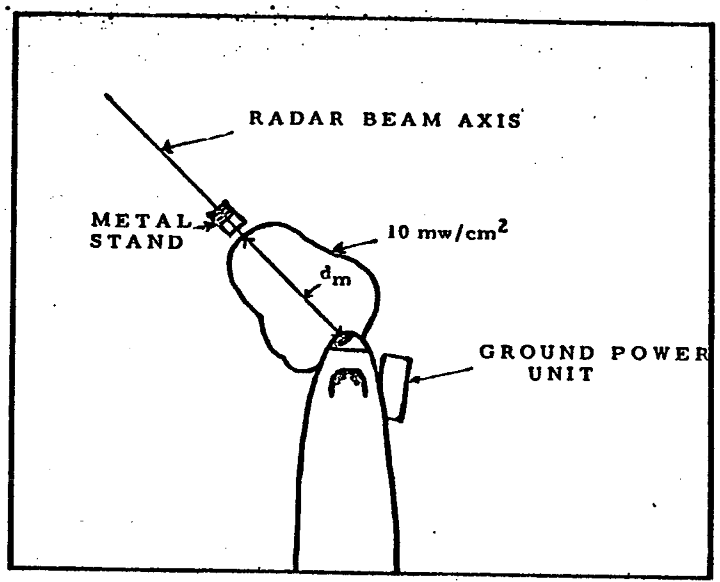

Figure 3. MAXIMUM SAFE ENERGY LEVEL PATTERN AVQ-10 RADAR (INSTALLED IN JET AIRLINER) 10 FEET ABOVE GROUND LEVEL—ANTENNA STOPPED.

Figures 3 and 4 show the pattern of the 10 mw/cm² danger zones around a typical jet airliner and a typical business jet. The pattern for the airliner is no doubt distorted by the metal stand used to raise the radiation detector up to the level of the antenna and by the ground power unit located on the forward right side of the aircraft. The energy levels found by measurement were generally lower than predicted by the calculations, but the MSEL was exceeded in the area near the radar antenna. The patterns shown are only examples. Individual patterns would vary depending on the state of "tune" of the radar and location of other objects in the near field. Local "hot spots" may occur at even greater distances than predicted by calculations.

While the antenna is scanning, the exposure time would be reduced; but persons subjected to repeated exposure for even short periods of time may suffer from cumulative effects. A particularly hazardous condition would exist while the antenna rotation was stopped as is sometimes done during ground maintenance procedures.

Most large manufacturers and users of microwave equipment have on their staff industrial optometrists, industrial physicians, safety officers or others who are aware of these hazards. The smaller firms do not usually have these personnel, and this is where the general optometrist can be of service in warning of the danger.

Radar has become more popular and

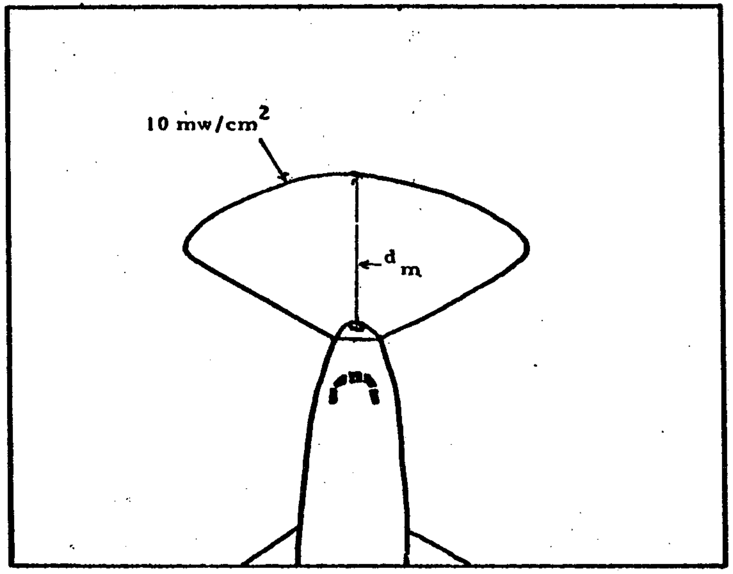

Figure 4. MAXIMUM SAFE ENERGY LEVEL PATTERN RDR-1E RADAR (INSTALLED IN BUSINESS JET) 5¼ FEET ABOVE GROUND LEVEL-ANTENNA SWEEPING.

more powerful. Its cataractogenic capability has been demonstrated. Since these changes are irreversible, prevention is of utmost importance.

The following recommendations are intended to prevent future microwave ocular lesions:

For the optometrist:

1. Patient education: Inform those patients working near radar and other microwave equipments of the hazards and suggest a review of safety standards and procedures. Monitoring of work areas may be advisable.
2. History: This may reveal exposure to radar or other sources of microwave energy. While this article discussed airborne radar, other sources are possible (microwave ovens and amateur radio microwave transmitters, for example).
3. Examination: Perform a thorough funduscopic and biomicroscopic examination, making accurate and detailed recording of all opacities. More frequent checks of exposed patients are desirable.

For the research, industrial or military optometrist:

1. Promote research to improve safety standards, particularly with regard to peak power, short pulse width and frequency effects.
2. Survey other sources of potentially hazardous microwave radiations.
3. Study the prophylactic or deleterious effects of various spectacle designs at microwave frequencies. Small metal frame components may have directive or concentrating effects at these wavelengths.
4. Develop protective devices. For those who must work in these hazardous areas, one should design hollow metallic tube "binoculars" of such dimensions (dia. $< \lambda/2$) as to operate in "cut-off" at the particular frequency used. These and other aids when used with proper shielding for other body regions could make it possible for personnel to work safely in a high-power-density microwave environment. AOA

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Discomfort Glare Research

Dr. Glenn A. Fry, right, regents professor, and Dr. Vincent King, optometrist and graduate in physiological optics, are currently doing research on discomfort glare. This project is being supported by the Illuminating Engineering Research Institute.

They are using an infrared pupillometer and a complex apparatus which can vary the state of adaptation to light and the size of the glare source, among other things. Drs. Fry and King are trying to assess the role of the iris in discomfort glare.