Radiation effects on man

From hair-dryers to color TV sets to microwave stoves—man-made products bombard man with a variety of radiation forms. The biological effects of this wide array of radiation and its interaction with the body are factors few of us will be able to ignore.

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MARY JONES is three months pregnant and works on a production line testing the regulation of high current power supplies. In preparing breakfast, Mary makes use of her automatic orange juice squeezer (sonic radiation). While drinking her juice at the kitchen table she uses the toaster, which is right in front of her (low frequency electromagnetic radiation). After breakfast, she puts the orange peels down the automatic garbage disposal (sonic radiation). While waiting for the bus, Mary finds herself across the street from a construction site where pile driving operations are taking place (infrasonic, sonic, and ultrasonic radiation). En route to work, the bus passes by an airport (sonic boom). At work she records data on high current supplies (static magnetic fields). At lunch Mary warms soup in a conveniently provided microwave oven (electromagnetic radiation). On leaving work, Mary heads for the dentist. En route she passes a construction site where blasting is going on (infrasonic, sonic, and ultrasonic radiation). Since this is her first visit to the dentist, she receives the usual diagnostic x-rays (x-ray radiation). Upon returning home, Mary sets her hair and dries it with her portable hair dryer (sonic and low frequency electromagnetic radiation). After dinner she watches her favorite color television programs (x-ray radiation) and often changes channels with a remote control (ultrasonic radiation).

Because Mary is pregnant, she is particularly susceptible to certain radiation forms. What is known of the potential hazards to Mary and her unborn child as a consequence of this day's exposure to man-made radiation? Research efforts have provided us with a significant, though incomplete, data base from which we may draw the answers to this question.

At present all sources of radiation are external to the body, though further complications may be expected as the development of implanted circulatory-assist devices and their associated power sources—nuclear, electromagnetic—reaches fruition. With the important exceptions of respiratory entry of contaminated air and the ingestion of radioactive food, radiation must pass through the external surface of the body in order to affect internal organs and body systems. The body surface protects the body interior hen it significantly attenuates the incident energy either y absorption or wave impedance mismatching or when ie temperature rise is sensed by the body surface sensors ı a time short enough to prevent internal organ damage. he effectiveness of these warning and protective mechaisms depends upon many factors: the form of the radiaon, its intensity, its duration, its frequency, and the ›lerable threshold of the organ, body system, or biological ıtity subjected to such radiation.

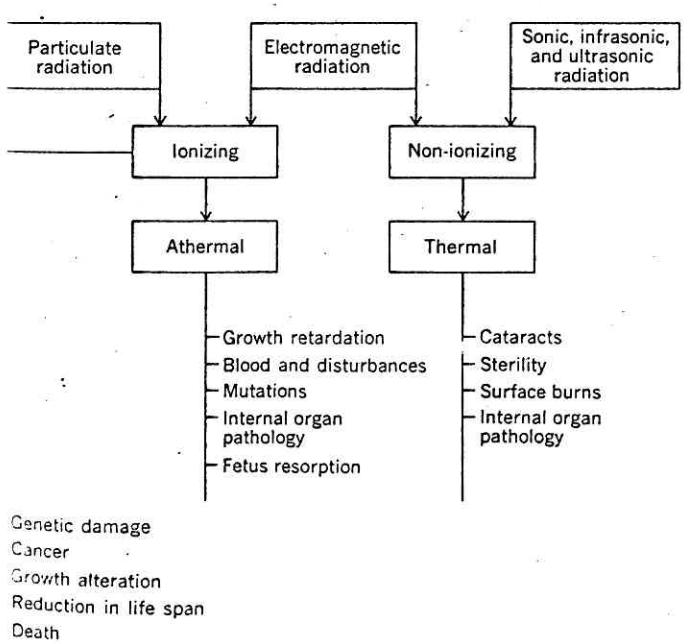
:lectromagnetic radiation 0 to 100 000 MHz

hermal effects. Hazards due to overexposure in the freuency range from 100 MHz to 100 000 MHz are priıarily related to heat development and subsequent temerature rise. The temperature rise may be a whole body :mperature rise or a local one confined to a portion of the ody system. The temperature rise is related to the followıg factors.[1]:

1. The specific areas of the body that are exposed to irıdiation and the efficiency with which they can eliminate ıis heat
2. Intensity, frequency, and duration of exposure
3. Thickness of skin and subcutaneous tissue

Schwan and Li[2] have characterized the body radiation bsorption process in a frequency range of 100 to 100 000 IHz and have set tolerance limits of irradiation levels. 'hey have shown that at frequencies well below 1000 IHz and at frequencies well above 3000 MHz, the perentage of absorbed energy is close to 40 percent and is lmost independent of skin and subcutaneous fat thickness.

lassification of potentially hazardous radiation inluding possible biological consequences.



In the range from 1000 to 3000 MHz, the percentage of airborne energy that is absorbed by the body may vary between 20 and 100 percent, depending on how thick the skin and subcutaneous fat are. Above 3000 MHz most is absorbed in the skin and causes superficial heating similar to infrared and sunlight; hence, the sensory reaction of the skin may provide adequate warning. At frequencies well below 1000 MHz, deep heating not indicated by the sensory elements in the skin occurs. Therefore, these lower frequencies should be considered more dangerous than their higher frequency counterparts. In the frequency range between 1000 to 3000 MHz, energy will be absorbed by both body surface and deeper tissues.

Measures of whole body temperature are not necessarily good indexes of local temperature rises. Organs that have poor blood supply or those which are subjected to partial body exposure, such as the brain, can rise to significant and even lethal temperatures without a significant whole body temperature rise. In addition, particular diseases and other complicating conditions such as metal objects contained within the irradiated individual can alter the tolerable thresholds. These metal objects may result in either a concentration of electric currents near their edges or reflection patterns that give rise to standing waves.

The eye is an example of biological tissue that is particularly susceptible to damage from microwave irradiation. Reasons cited[3] include the eye's low efficiency in eliminating heat *via convection,* a consequence of its poor blood supply, and its inefficiency *in conducting* heat away due to its proximity to several cavities. An additional possibility is that the irradiating energy is dissipated to a large extent in a very small thickness of the eye as a consequence of the high conductivity of the eyeball fluid. Often cataracts result.

Athermal effects. Athermal phenomena occur when a magnetic or electric field interacts with a complex conductive, dielectric material and include:

- The generation of electromagnetic force in moving conductors, which may result in electrolytic dissociations affecting the nervous system
- Forces exerted upon moving charges, which can alter the motions of ions in an electrolyte, leading to distributions other than normal ion concentrations
- Torque and forces exerted on permanent magnetic dipoles and nonspherical paramagnetic or diamagnetic particles such as blood cells.

Indeed, much is yet to be learned as to which of the above phenomena is the predominating factor in producing or initiating the observed biomagnetic effects. Examples of stress phenomena include: retardation of growth of young mice, hematologic changes, retardation of wound healing and tissue regeneration, effects on central nervous system, decrease in body temperature, disappearance of the oestrus cycle, resorption of the fetus in the uterus, decrease in tissue respiration, pathological changes in liver, and altera-

Table I[10]. Athermal stress phenomena

Field sensitive phenomena	Oersted
Magnetophosphenes	200
Central nervous system (rabbit)	800
Embryo resorption (mice)	3000
Retardation of development	4000
Enzyme activity change	5000
Change in O_2 consumption and degeneration of sarcoma cells	8000
Gradient sensitive phenomena	**Oe/cm**
Lethal effect (mice)	5000
Lethal effect (drosophila)	6000
Arrest of tumor growth	15 000

Table II[11]. Erythema dosages

X-ray	Doses to produce erythema
12kV	100 R
100kV	350 R
200kV	600 R
1000kV	
1860kV	1500 R
Beta radiation	1000 rads
Fast neutron radiation	660 REM

Lethal dose rates after exposures of less than 24 hours which have resulted in death in 30 days or less of 50% of exposed subjects are set forth as follows:

X-rays	400 R; fast neutrons: 400 REM
Beta	Beta particles with energies less than 10 MEV will be completely absorbed before reaching the depth of the blood forming organs (5 cm)

tion in sensitivity to other types of radiation.

It would appear from both theoretical and some experimental data that the observed biological effects are proportional to the product of field strength and exposure time, or to field gradient times exposure time. Table I is a summary of experimental data.

Ionizing radiation

At the other end of the spectrum we have X- and gamma rays (occupying the electromagnetic frequency range from 10^{16} Hz and up) and other high energy particulate radiation (alpha, beta) that may collectively be referred to as ionizing radiation, although other forms can ionize as well. Well-defined systems of classification of energies and dose rates have evolved. The fundamental unit of exposure is the roentgen (R), defined as the quantity of X- or gamma radiation that will release one electrostatic unit (ESU) in one cm^3 of dry air due to ionization of the air. This corresponds to an energy absorption of approximately 88 ergs/g. The unit of absorbed dose is called the *rad*, which corresponds to an energy absorption of 100 ergs/g of absorbing material. This, however, is an insufficient criterion of biological effects since the distribution of the ionization along the path of a charged particle is also significant. The density of ionization along a particle track is expressed in terms of the rate of linear energy transfer (LET), which in a given material is a function of the charge and velocity of the particle. Hence, radiations which give rise to particles with different LET characteristics for the same absorbed dose will differ in their relative biological effectiveness (RBE). The biological effectiveness of a dose of a given kind of radiation is expressed in roentgen equivalent man (REM). The dose in REM is the product of the physical dose (rad) and the appropriate RBE factor.

These ionizing radiation forms may result in loss (enzymes, hormones) or alteration (nucleoproteins, chromosomes) of critical materials and an increase in decomposition products. These effects can lead to a disturbance of the mitotic cycle and the accumulation of toxic substances and cell death.

Perhaps the most common of the early signs of skin damage is erythema or skin reddening. Table II indicates the variability in dose to produce erythema.

In addition to these effects, ionizing radiation can produce eye cataracts and cause sterilization. The radiation dose to cause sterilization in the male is 800 to 1000 R to the testes and in the female 400 to 600 R to the ovary. Table III summarizes some maximum permissible radiation dose rates for man.

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Infrasonic, sonic and ultrasonic radiation

Effects of sonic, infrasonic, and ultrasonic radiation represent additional sources of potential biological damage. One form receiving a great deal of publicity of late is the response to sonic boom, which may be arbitrarily described[4] as physiological or psychological in nature. To date, no direct personal injury resulting from sonic booms has occurred. White[5] has set forth threshold criteria estimated to be near conditions at which casualties will approach a minimum or be absent. The estimated threshold 'able III[11]. Maximum permissible radiation dosages for nan

)rgan	Dose rate
rain, eye lens	5 REM/year (average)
;onads, whole body	12 REM/year (maximum)
	3 REM/13 weeks
hyroid	30 REM/year
kin	10 REM/year
	6 REM/13 weeks
,ngs, bone, kidney	15 REM/year
,nkle, foot	75 REM/year
	25 REM/13 weeks

)r value of overpressure is 15 psi for lung damage and 5)si for eardrum rupture. Nixon[4] has compared the mea-ured values of overpressures due to sonic boom and ound them to range from 0.14 to 0.83 psi for low flying ircraft and generally in the range of 0.0035 to 0.35 psi or sonic booms from normal operational altitudes.

At the lower end of the vibration spectrum, we find that he data available on the biological effect of infrasonic below 20 Hz) and low sonic frequencies is relatively parse. Wever and Gray[6] reported slight dizziness, nausea, ınd a feeling of apprehension during exposure to stimuli of 15 to 17 Hz. Von Gierke[7] reported on the threshold of)ain for the ear exposed to infrasonic tones of various fre-quencies. His data establishes this threshold at 179 dB at ero frequency, 165 dB at 3 Hz, 140 dB at 15 Hz.

Middle ear changes noted among German submarine liesel-room personnel have been attributed to the infra-onic and very low sonic fields caused by the engine cylin-lers. Mohr and others[8] appear to have performed the first systematic evaluation of the biological effects of low sonic ınd infrasonic vibrations on humans. They studied six bio-ogical parameters expected to be responsive to nonaudi-ory effects. The most prominent effects attributable to the nfrasonic noise spectra occurred during exposures without ear protection. Pressure buildup in the middle ear oc-curred, along with tympanic membrane tickle, nostril vi-)ration, and abdominal wall vibrations. Pressure levels were between 125 and 150 dB. Maximum intensity, very low sonic frequencies (approximately 135 dB) produced moderate chest wall vibration, a sensation of gagging, per-ceptible visual field vibration, and some middle ear pain. In the range 50 to 100 Hz, subjectively intolerable envi-ronments were produced, with responses that included coughing, choking, headaches, visual blurring, and fatigue.

Each of the experimental efforts is representative of the ways in which mechanical forces can act on a biological system. Von Gierke[9] has attempted to lay the foundation for a unified treatment of the biological effects of mechani-cal forces by classifying air and structural vibrations as to (a) the mode of force transmission, (b) the time function and hence frequency spectrum of the applied force, and (c) the specific biological reaction of concern.

Research needs

Recognition of the magnitude and diversity of man-made radiation sources is a first step to the development of appropriate methods whereby their associated biological hazards may be diminished. The nature of the interaction of various radiation forms with biological systems depends on such factors as frequency, intensity, duration, and tolerable threshold of the biological entity subjected to the radiation.

Intense research is needed in the following areas:

- Chronic dose optimization criteria for ionizing radiation.
- Tolerance of individual internal organs and body systems to heat production as a consequence of electromagnetic radiation in the human. Of particular concern are those organs and systems having either inefficient heat elimination capability or particular sensitivity to temperature rise as a consequence of anatomical position, a physiological limitation like a poor blood supply, or a pathological condition such as atherosclerosis or chronic kidney disease.
- The effect of exposure to low frequency electromagnetic fields, with particular emphasis on their effect on infertility in women, pregnancy, the central nervous system, child growth, and the pathology of specific organs like the liver.

Radiation can aid diagnosis, relieve suffering, and prolong and save life. In the minds of many, however, the ever increasing number of man-made devices and systems represents sources of potentially hazardous, uncontrolled radiation. The biological effects of this wide array of radiation forms and its modes of interaction with the living system are factors few of us will be able to ignore.

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