COSMIC RADIATION AND ITS BIOLOGICAL EFFECTS

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ABSTRACT

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A summary review of the radiations in space and their effects. The categories of primary cosmic, solar flares, Van Allen belt trapped particles, and secondaries are discussed in terms of flux and location of these radiations. The biologic effects of ionizing radiations are discussed in brief, comparing the acute and delayed effects. It is pointed out that doses necessary to produce significant damage are well in excess of those normally to be found in the space environment.

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Above the earth's surface lies an environment called Aerospace. This environment is generally and roughly divided into the Atmosphere, which is of great importance to us because of the air content which has supported our life forms, and Space, which begins at the outer limits of the atmosphere. The region beyond an effective air supply begins at about 50,000 feet (9.5 miles) where the oxygen pressure has been reduced by about 90%, as compared with that at sea level (1)

For many years it was though that the environment of the far reaches of space was calm, empty, and monotonous. Certainly we are now aware that such is not the case. We now know of terrestrial radiation belts, nigh sky emissions, cosmic radiation, solar flares, meteorites, corpuscular radiations, radio emissions and we are no longer surprised at new discoveries as they are announced. It is with the radiations of space and their effects that this discussion is concerned.

I. Space Radiations

The radiations in this space environment can be classified in four general categories:

1. Primary cosmic radiation.
2. Solar radiation bursts.
3. Van Allen trapped radiation.
4. Scattered, or secondary radiation.

And, each will be outlined briefly as to identity and characteristics.

Cosmic radiation has been known and studied since its discovery prior to 1911, and the postulation that they were of cosmic origin in 1913. The study has involved many approaches, from ascent of the Eiffel Tower, and balloon flights, to more recent orbital and deep space probe vehicles.

Primary cosmic radiations consist of particles which are mainly chemical atoms, usually completely ionized, which possess energies ranging from a few million electron volts (Mev) to upwards of 10 billion electron volts (Bev). The relative composition of cosmic rays is given by Table I (2)

TABLE I

Relative Chemical Composition of Cosmic Rays

Atomic Number	Element	Relative abundenace (H=1)	Percentage
1	H	1	80
2	He	0.1	19
3,4,5	Li,Be,B.	0.001	0.1
6,7,8	C, N, O.	.005	0.7
9 - 30	F - Zn.	.002	0.2
31 - 92	Ga - U.	$<$ .00001	0

Cosmic radiation of galactic source is omni-directional as observed from the earth and apparently constitutes a fairly homogeneous distribution throughout space. The intensity of these radiations reaching the earth, however, is quite different at various latitudes and this variation is dependent upon the magnetic field of our earth. To reach the equator, a particle needs an energy in excess of 15 billion electron volts; to reach the earth at a latitude of 50°, about 6 billion electron volts, and to reach one of the polar regions, slightly in excess of 4 billion electron volts. Particles with energies less than 4 bev are deflected by the magnetic fields.

The second category of radiations includes those of solar origin. This emission of proton beams from areas of observed sunspot activity has been considered one of the main radiation problems of manned flight in space. Even though the total energy content of this radiation is small compared to that in the visible spectrum, it is still large enough and variable enough in both quantity and quality to be of concern in terms of hazard and protection.

Solar flares are large chromospheric eruptions on the surface of the sun which may accelerate particles to the billion electron volt range of energies. They are classified according to the area of the flare on the visible hemisphere of the sun, and as the area of the flare increases, the flare is said to increase in order of importance. For example, an importance 2 flare covers an area on the sun larger than the surface of the earth. The incidence of flares of varying importance is given in Table II, as derived from incidence of flares in the period from 1947-1953 (3).

TABLE II

Frequency of Solar Flares

Importance Value	Mean No. Flares/24 Hr
< 1	10.
> 1	2.
> 2	0.3
3,3+	0.05

A major solar flare event may be an extremely hazardous phenomenon to men and material in outer space. Flares measured as high as 5,000,000,000 protons/cm^2, at energies of 30 million electron volts, gives calculated radiation doses in free space of approximately 3000 roentgens gm/cm^2. The shields expected in space flight will provide considerable protection, but not totally.

The third category of radiation in space is that found trapped by geomagnetic forces in the Van Allen Belt. It consists of energetic electrons and protons trapped in the geomagnetic field in two spatially separated high-intensity doughnut-shaped zones of radiation (Fig. 1).

INSERT FIGURE 1

VAN ALLEN BELT RADIATIONS

The inner belt consists of penetrating proton and electron components. The electron energies range from 200 to 1000 thousand electron volt, and the protons from about 75 million electron volts at the low altitude margin down to about 10 million electron volts at the distant edge. The inner zone begins at about 600 Km in the equatorial plane and extends out to about 10,000 Km, with the maximum intensity centered at about 4000 Km. It is essentially stable with respect to time in that it is not greatly affected by solar activity.

The outer zone consists of electrons in the energy range from 500 to 5000 electron volts, and soft protons with energies less than 1 million electron volts. This outer zone begins at about 15,000 Km in the equatorial plane and extends to an altitude of about 70,000 Km (Fig. 2). (4).

INSERT FIGURE 2

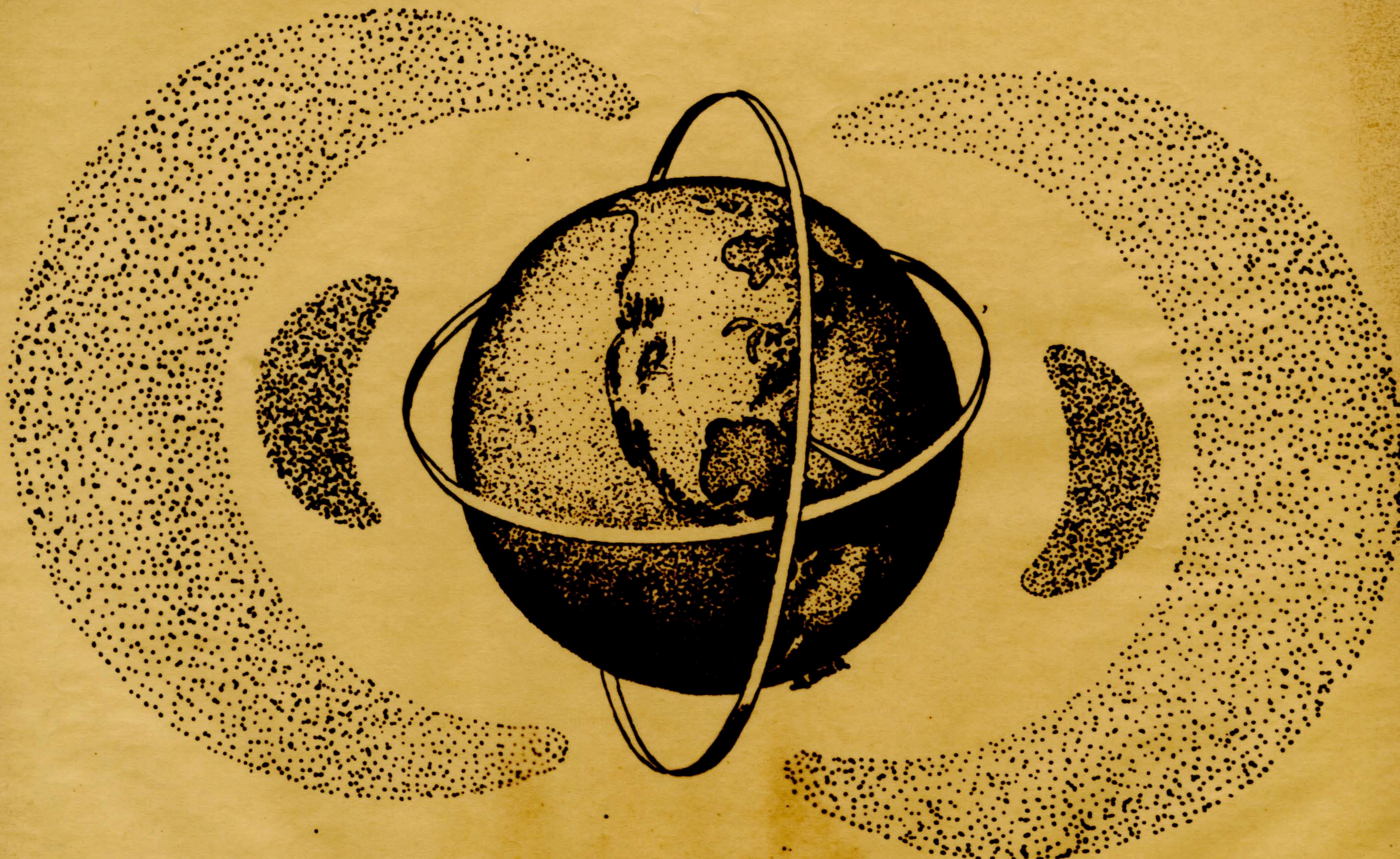
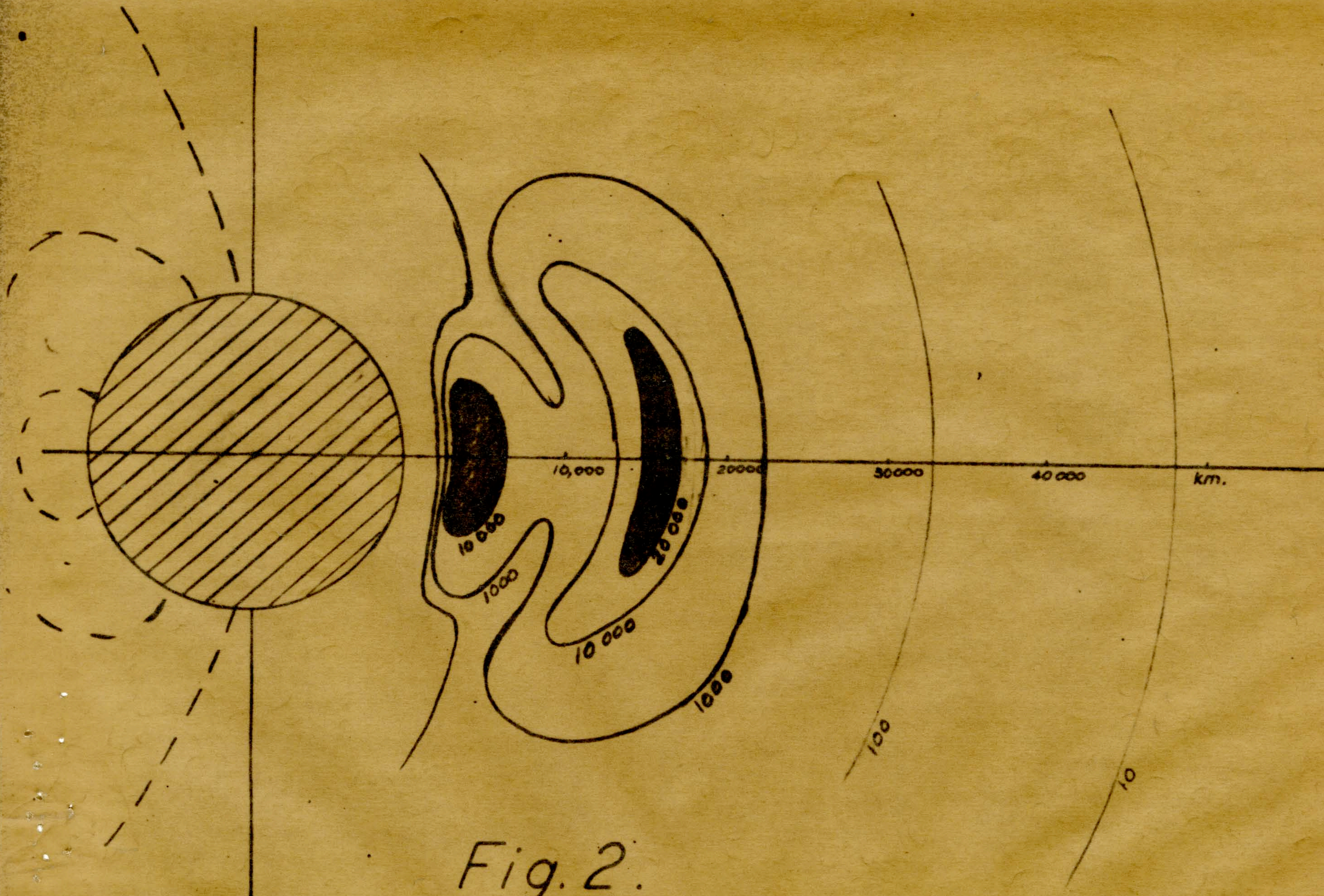


Fig. 1.



10,000
20000
30000
40 000
km.
10 000
1000
20 000
10 000
1000
100
10

Fig. 2.

The outer zone varies considerably in intensity and location, with extreme fluctuations associated with high solar activity.

Below 600 miles of altitude the radiation levels are apparently relatively low, and approximate the estimates of background cosmic radiation. However, there is considerable latitude - latitude dependence and thus the recorded measurements represent a relatively small area in the space environment.

The fourth category of radiations, while not of great importance in free space, may well become one of the most significant factors when men and materials are placed in the ambient radiations. This category includes all the secondary forms of lesser energy radiations which result from the interactions of the energetic primary radiations with any form of matter, including biologic tissue. Since this secondary radiation is of lower energy, more of it is likely to be absorbed in the tissue or individual, thus producing a higher absorption dose than expected from particles in the million and billion electron volt ranges.

Having reviewed the types and origins of radiations, let us compare the expected dose rates of radiation. Based on balloon and Pioneer V data, it appears that background galactic radiation corresponds to approximately 1 rep/hr (5). In the Van Allen Belts, according to Schaefer (6) travel periods of about one hour would give an astronaut doses of approximately 5 r for each trip. At 3-4 earth radii the geomagnetic effects are minimized and the ambient galactic radiation amounts to about 25 milli rep/day or 9.5 rep/year (5).

The magnitude of the solar flare problem is realized when calculations of the dose to an unshielded man if exposed to a 3+ flare such as occurred on 10 May 1959, show that the exposure would have been about 1500 rep (5).

II. Effects

The radiation effects which are noted in most interactions of ionizing radiations with matter are those which result from the transfer of energy from the incident radiation to the matter traversed. This may sound simple, but the difficulty lies in describing the transfer of energy from the radiation to the system in which the effect is to be observed and measured.

The ratio of the biologic dose to the energy absorbed per gram involves the conversion known as relative biologic effectiveness, and this relation has been studied and reported extensively (7). This ratio is variable, and depends partially, at least on a) type of radiation, b) radiation energy, c) kind and degree of biological effects, d) type of biologic material, e) dose distribution total, time rate, and intervals, f) other factors such as temperature, oxygen, etc.

Excessive exposures to radiation can result in early acute changes such as nausea, vomiting, diarrhea, and fatigue, and higher doses to the entire body can produce death within days or weeks.

The radiation effects from single-exposure radiation to essentially the total body of a biological system seem to fall into a pattern that can be called an acute radiation syndrome. This pattern is essentially similar for various species of animals, although individual species show characteristic modifications which are a function of their own physiology. In man and the primates a very definite pattern of radiation-injury symptomatology occurs after a certain level of radiation dosage is delivered to the entire body in a single or short-term exposure. This acute radiation syndrome has been described adequately in the literature and is believed to be effective mainly at dose levels above 200 r total-body radiation.

Under 200 r total-body radiation a very small percentage of individuals exposed will show any effect of radiation, and these effects will usually be mild and transitory. At dose levels above 200 r, the severity of the radiation effect increases, and a greater percentage of the individuals is involved until finally, on a biostatistical basis, a radiation dosage can be reached at which all individuals can be expected to show changes. Some of these changes will produce death if the doses are high enough and the number of individuals exposed is large enough. Death may be the predominant result at very high doses. These changes are categorized in Table III.

TABLE III

Acute Effects, Total-Body Radiation

$<$ 200 r	No clinical significance
3-600 r	Hematopoietic depression and depletion
500 r	L-D 50%
6-900 r	Gastrointestinal form of death
$>$ 1000 r	C•N•S death; Incapacitation

These changes, described with reference to an administration of a single dose of radiation of varying levels of dose amount, are fairly well established. However, if the total dose administered is given over a period of time extending over two or three days instead of a single dosage exposure, the expected effect may be diminished from the pattern described by as much as from 25 to 30 per cent. Some of the effects observed may be reduced to even a greater degree. The radiation effect pattern or syndrome shows rather marked individual variation. It has been noted that the psychic effect of observing others exposed to the same radiation dose, such as has occurred in certain human population exposures, is also effective in increasing the observed effect in some individuals.

The effects of radiation may be fairly prompt or may be delayed by weeks, months, or even years. Classic examples of late effects of radiation have been reported repeatedly. Usually they are associated with degenerative changes in the tissue substance which culminate in failure of certain organ systems. The degeneration may be such that it allows the onset of an otherwise mild infection to become serious and even overwhelming. Other late effects may result in formation of tumors, alteration of life span, leukemia, and effects such as cataract formation in the lens of the eye, pigment change, hair-color change, and the like.

The evaluation of long-term effects or delayed effects of radiation is extremely difficult because of the requirement of observing significant numbers of individuals over a sufficiently long period of time and because of the necessity of having sufficient control of the population sample followed to assure that the effects noted are due to radiation rather than to other environmental factors. Since the effects noted are essentially similar, except in incidence, to those which normally may occur in the population observed, it sometimes is difficult to measure accurately the exact effect of radiation in the production of the end point noted.

It is evident from the previous discussion that the estimation of the radiation hazard to biological tissue depends on many variables. This estimation must also be made in terms of the operation requirement of the exposure to the radiation (8).

Considering present knowledge, it is reasonable to suggest that a dose of 25 rad be permitted per operational space mission, with 25 rad to be reserved as an additional emergency dose, for error in orbit, unusual regions of radiation intensity, or an unpredicted solar flare. The estimation of the delayed effects of such suggested doses contains much uncertainty, but probably no more than exists in the combinations of vehicle reliability in launch, navigation, and return. The estimates considered to be reasonable are presented in Table IV (9).

TABLE 4

Radiation Dose vs Biologic Effect

	Year:	1	3	5	10
	Rad:	50	95	130	200
Leukemia		3x	6x	9x	12x
Longevity		?	?	1	1-2 yr
Sterility		0	0	0	?
Cataracts		0	0	0	0
Genetics		2x	3x	4x	5x

The biologic effect of radiation is no single effect, nor is the effect specific for radiation. Similar effects can be produced by other agents or combinations of agents. Also, the biologic effect observed in any one individual is peculiar to that individual both in degree and time response. The degree of hazard must be evaluated not only in its own right, but in comparison with other hazards that are also involved in the life situation and in the operational requirements.

The viewpoint of persons concerned with control and interpretation of radiation exposure must be based on education, experience, and understanding. Radiation must be considered essentially as an additional factor of hazard in one's life, on the ground, in the atmosphere, or in space. By itself, radiation is not the limiting factor to human participation in progress.

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