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# BIOLOGICAL ASPECTS OF NUCLEAR PROPULSION

by

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Feasibility of peaceful uses for atomic power have been under study for many years. Nuclear propulsion for vehicles presents many engineering and designing problems. However, careful evaluation also reveals a series of medical problems resulting from the power plant, or more specifically, from the nuclear radiations associated with the operation of the power plant.

This paper discusses the problems of permissible levels of exposure to pure and mixed ionizing radiations in terms of acute as well as chronic exposures. Biological endpoints of concern are demonstrated and threshold doses considered.

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The use of nuclear energy is one approach to possible extension of a nonstop, nonrefueling long-range navigation capability for aircraft. This becomes obvious when we compare the energy with which a single neutron or proton is bound to a nucleus to the chemical energy released in the ionization of hydrogen atoms -- $7 \times 10^6$ e.v. to 13 e.v. In this concept a nuclear reactor would replace the chemical fuel system so far as cruise is concerned thereby eliminating the fuel limitation problem. In this same context, nuclear processes applied to the ramjet principle afford a means of achieving greater airspeed, or Mach number in the high supersonic speeds and at high altitudes (1,2). Extending this propulsion aspect from semiconventional high-performance airframes into the fields of missiles and rockets may greatly increase velocities and lengthen the operational period for missiles. Present propulsion systems would not become obsolete since they would still serve as boosters for take-off or launch and for acceleration during the early moments of flight to minimize radiation contamination. With an almost inexhaustible source of fuel, earth orbiting satellites would be possible for use in weather observation and forecasting as well as hurricane and typhoon steering. Furthermore, the residual build-up of fission products from the main power source affords auxiliary heat or power to assure that the data gathering and telemetering instrumentation will last during the potentially long period of satellite usefulness. When complete escape from the earth's gravitation field is desired, such as would obtain for lunar probes, flights around the moon, or complete escape from the solar system, nuclear reactor energy igniting liquid hydrogen fuel for thrust may indeed become the most practical and expeditious means of propulsion.

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Finally, if men of vision are correct in their predictions of the future, so-called space stations and refueling stations for extended space flights will doubtless require unlimited self-contained fuel and power sources in maintaining flexibility in changing flight paths or orbits. Nuclear fuel may indeed, in this way find its greatest preacetime application.

The decision as to choice of propulsion systems is more complex than just the consideration of energy utilization. Nuclear energy, as it is released is a tremendous force, but coincident with its release is the release of ionizing radiation. Radiation actually begins with the elementary process of fission. The fission fragments thus formed are intensely radioactive and decay by a succession of particle emissions and conversion accompanied by gamma radiation. Additionally, the active fission itself releases high-energy gamma radiation. Further, propagation of fission requires neutrons which in turn may become radiation hazards either as stray neutrons or by inducing artificial activity into the previously stable components, components of the airframe and surrounding atmosphere. These ionizing radiations of varying energy can and do penetrate matter. They can penetrate the human body without being sensed. By a process of ionization they attack living cells and can produce serious illness and even death over a period varying from days to years. It is important and imperative therefore that a real appraisal of the biological hazards, the dose effect, and the response to the various radiation sources be well understood, if realistic permissible levels of exposure are to be determined. There must, however, be a careful balancing of potential radiation risk against



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the total benefits to be obtained, since we cannot eliminate total risk from anything man does.

Exposure to reactor radiations, when in sufficient doses, can produce in man certain rather specific and well-defined responses. Data obtained from among the peoples of Hiroshima and Nagasaki, the few accidental exposures to Atomic Energy Commission personnel, and extensive laboratory experiments reflect the typical acute radiation responses but not the latent effects from prolonged exposures to low levels of radiation. In this regard, the effects may not be manifest immediately but rather only after a prolonged period of time; hence, extreme care must be exercised in suggesting maximum permissible levels of exposure.

Among the more immediate effects are the decrease in white blood cells soon after radiation exposure (Fig. 1); on or near the 5th post-radiation day, erythema (Fig. 2); at 15 days, epilation with a subsequent regrowth of hair (predominantly gray in color) (Fig. 3); and at 30 days, a desquamation and pigment proliferation (Fig. 4) (3). Lens opacities frequently appear after several months especially after exposure to fast neutrons (Fig. 5) (3). Late somatic effects from relatively large, near-fatal doses of radiation appear as mature cataracts (Fig. 6), in certain instances as leukemias, and in shortening of the life span (Fig. 7). For the most part, however, sub-lethal doses -- less than 460 to 600 r (the acute lethal dose for half of a given population) but greater than 150 r -- are required to clearly produce these radiation effects (Fig. 8).



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So far, consideration has been focused on acute exposures to near lethal levels, but what of the much smaller doses given intermittently over relatively long periods of time? Experimental data do not substantiate the typical acute radiation responses; certainly there is an absence of erythema, epilation, lens opacification, and desquamation. The drop in white blood cell count is much less severe (Fig. 9); there is, however, a loss in cellularity in the bone marrow (Fig. 10, 11), but both of these responses disappear when radiation is removed and repair is allowed to ensue. This is true even when the dose ultimately accumulates numerically to much greater than the so-called $LD_{50}^{30}$ dose.

Even though the acute dose schedules discussed and the even greater protracted doses (Fig. 12) do not yet demonstrate irreversible biological damage, it is indeed true that these doses may have harmful biological consequences which are more subtle. Such emphasis has been placed on possible effects such as increased susceptibility to bone cancer and leukemia, a shortened life span, and harmful mutations that the public has become deeply concerned about them. All genetic information currently available leads to the conclusion that the increase in genetic mutations is proportional to the total dose (4). If this be true, a radiation dose of 2X must be presumed to be twice as harmful as a radiation dose of 1X; but we still do not know the amount of harm being doubled. Nevertheless, most mutations are harmful and since we have no way of establishing the doubling mutation rate in man except from other species, best estimates indicate that a doubling human mutation rate, after an accumulated



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dose during a generation, is in the range of 30 to 80 r. This is by far the smallest number yet defined in the development of dose vs. irreversible detrimental effects.

So far as life span is concerned, much evidence points to the fact that large doses of radiation significantly shorten longevity; on the other hand, very meager data on low doses for very long exposure do not show significant reduction in life span. The several mathematical models which permit extrapolation down to very low doses and suggest that life is shortened a few days to a week per roentgen, have been examined recently in light of the available data. In fact, Mole (5) points out that from the very, very few points in chronic exposure to low weekly doses -- 10 r -- three different curves fit the data near equally well and one of them leads to the conclusion that there is a threshold at 1 to 2 r per day below which no shortening of life exists. Other experiments demonstrate that exposure to small doses of radiation increases life expectancy. Warren, in a survey of deaths of 82,441 physicians reported between 1930 and 1954, found that radiologists die on the average 5.2 years earlier than other physicians. Furthermore, nonradiology specialists known to be exposed in a limited way to radiation also show a definite shortening of life but less than that of a radiologist. One might then conclude that exposure to ionizing radiation is the predisposing factor in this shortening of life (6). Lewis (7) in re-evaluating the above data concludes that when properly age-corrected the radiologists' longevity is somewhat greater than that of the other groups. This



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clearly demonstrates that information as to what small doses of radiation will do to a complex organism like the human is still far from definitive (8).

It is now generally agreed that an increased incidence of leukemia can follow acute or chronic exposures to ionizing radiation. By the end of 1956, hematological studies in Hiroshima showed that an increased incidence of leukemia was related to the distance from the A-Bomb hypocenter and to the occurrence of the acute radiation symptoms. Furthermore, an elevated case incidence in 1950 has shown no conclusive evidence of decline as yet (9,10). Leukemia in 1950 killed 3.9/100,000 of our total population over 20 years of age, while from 1950 to 1954 120 physicians died of leukemia, an average annual rate of 11.2/100,000. The death rate for all physicians was about 3 times that of the adult population. As would be expected, leukemia shows a higher percentage among radiologists. Once again, however, it is difficult to establish a linear dose-response relationship. Evidence strongly suggests a threshold dose or, if you will, a "minimally effective" dose (11) of 200 r below which no detectable increase in leukemia incidence has been noted.

Radiation, as we know it today, can produce biologically detrimental responses. It is quite clear, however, that so-called threshold doses or, better, minimally effective doses do occur for every end point of concern with the greatest question surrounding possible genetic effects. If, in spite of this area of doubt, it is reasoned that a limited number of carefully selected persons will be involved in space operations, it becomes obvious that dose schedules can be



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quite reasonably defined.

A careful comparison of many human exposures from among Japanese survivors, Marshall Islanders, and groups of cancer patients receiving therapeutic x-radiation reveals certain points in common. The one point of interest here suggests an individual sensitivity to ionizing radiation. Although there is, in general, a marked variability, in one specific instance, large numbers of persons were exposed under almost identical conditions and these data lead to the conclusion that extremes in susceptibility differ by a factor of about 2. For example, among people exposed to 200 r, the most sensitive would develop a clinical picture of the same severity as that exhibited by the most radioresistant person exposed to a dose of 400 r (12). Since it is clearly demonstrable that radiation response is indeed a function of dose as well as individual sensitivity, an exposure of 150 r to a select group of mature individuals may produce only a mild clinical case of the acute radiation syndrome. The risk of shortening life and the increased susceptibility to leukemia are far less than the risk in the overall reliability of the satell-orb system. On the evidence given above it should be reiterated: The limited risks involved must be carefully balanced against the benefits to be gained.



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