EXPERIENTIA

Volume 45/No. 1 Pages 1–114 15 January 1989

Radiation effects on man and animals

The Editors wish to thank Prof. Hedi Fritz-Niggli for coordinating this review.

Introductory remarks

The science of radiobiology first came into being in the first months of 1896, but of course living matter on earth has been confronted with the fact of radiation from the beginning of life itself. Life is not comprehensible and not even possible without the phenomenon of radiation. It has bearing not only on the way organic matter is produced, but also on the creation of diversity (evolution) and the recovery of living matter from insults.

The significance of research on the effects of radiation on living matter and man is threefold, as it

- investigates the application of radiation and radionuclides for human health
- facilitates the evaluation of radiation risks, and
- yields fundamental insights into significant life phenomena.

In the field of human health, the application of radiation and radionuclides has primarily been seen in the battle against cancer, and in the diagnosis of pathological changes in structure or function of tissues.

More than one third of all cancers are cured by radiotherapy. With view to optimizing radiation therapy, two fields of enquiry are suggested for radiobiological research: a) the employment of new types of radiation, mainly very densely ionizating radiation, and b) the application of injury radiosensitizers (including hyperthermia) to malignant cells, and of radioprotectors to normal cells.

The physical interaction of radiation with living matter provides a means of diagnosing pathological structures, but also of investigating normal functions and structures. Apart from the physical interaction, the biological interaction with living cells – even in the radiodiagnostical application of radiation – poses an important problem to human health.

Radiation protection, starting with the evaluation of radiation hazards, represents the second duty of radiobiology. An immense amount of work on estimating the action of low and high radiation doses has been done, and serves not least as a model for risk studies of other nocuous (primarily environmental) agents. As the Chernobyl disaster showed, there is a categoric need for the public to be better informed by the science sector.

The third area for which radiobiology is of special significance is basic research. Important phenomena of life, such as development, mutation in DNA, and transformation of normal cells into malignant ones could effectively be elucidated by means of radiation. In this context one thinks of how the whole field of genetics was fertilized by the discovery (mainly by Muller) of the mutagenic action of radiation.

In the last 30 years, radiation biology has developed in an impressive manner. The replacement of older doctrines and theories by modern hypotheses and the revelation of new facts continue to produce surprises and sources of concern.

The aim of the contributions to this review will be to give some insight into the most recent problems of radiation effects on man and animals.

The chain of events following radiation damage is long but always initiated by physical mechanisms, as the first paper by H. Blattmann ('Radiation physics') shows. The interaction of radiation with matter is treated in a rather unusual manner without complicated mathematics. The results of analysis by physicochemical and biochemical methods of the mechanisms of the events after radiation energy absorption are found in U. Hagen's broad survey, 'Biochemical aspects of radiation biology'. The paper 'Studies of the dose-effect relation' by A. M. Kellerer is of major interest not only for basic radiation research but also with respect to questions of radioprotection as low dose effect. In recent years, the role of repair in the final expression of radiation damage has become most important. T. Alper and W. A. Cramp discuss this interesting subject in their contribution. The connection of 'Cell kinetics and radiation pathology' is described by J. Denekamp and A. Rojas who present not only the best methods but also the newest results on differences between tumors and normal tissues. 'Modifiers of radiosensitivity' by the same authors are pertinent to radioclinical questions and problems of radiation risk. On the subject of genetic damage, J. R. K. Savage discusses 'The production of chromosome structural changes by radiation'. This damage has been connected to important radiation risks for human health, like cancer induction. Important

elucidation on the subject of carcinogenesis is offered in the study 'Radiation carcinogenesis in experimental animals' by J. J. Broerse, D. W. van Bekkum and C. Zurcher. The field of radiation damage on animals is rounded off by C. Michel with the contribution 'Radiation embryology'. Damage to proliferating organisms is one of the most impressive effects of radiation.

I very much thank my friends and colleagues for having written such remarkable and excellent contributions to clarify the complex effects of radiation on living matter.

Hedi Fritz-Niggli

0014-4754/89/010001-02$1.50 + 0.20/0

Radiation physics

H. Blattmann

Department of Radiation Medicine, Institute Paul Scherrer, CH-5234 Villigen (Switzerland)

Summary. A review is presented of the recent literature in the areas of physics which deal with radiation effects on man and animals. Some consideration is given to natural and artificial radiation sources such as cosmic rays, radon and high energy accelerators. The interaction of radiation with matter is treated if it is related to an energy deposition pattern relevant to biological effects. Dosimetry is also treated, with special emphasis on papers dealing with spatial dose distribution on a microscopic level, and radiobiological models relating the energy deposition pattern to biological effects are cited. New techniques in the medical application of radiation in diagnostics and therapy are briefly mentioned.
Key words. Radiation sources; energy deposition; charged particles; dose; models; medical applications.

Of the many types of radiation, which – even if only electromagnetic waves are considered – range from radiowaves over microwaves, heat, visible and ultraviolet light to X-rays and gamma-rays, this article is concerned only with ionizing radiations.

Radiation sources

Natural radiation sources

Since the big bang, the universe has been filled with radiation, and the earth is bombarded continuously by particles and photons from space with different frequencies and different origins [1, 24, 82–84]. The most abundant particle is the proton, but, nuclei up to the mass of iron are also present in the cosmic radiation, although with lower frequencies. For manned space flight these may be as important as protons because of their higher ionization densities [54]. Depending on the type and energy of the radiation, the magnetic field of the earth and the atmosphere act as a shield, eliminating some of the particles completely and reducing the intensity of others. The earth is therefore protected from the large showers of particles which traverse space. The mathematical description of these radiation fields is the aim of some of the recent papers [82, 83]. For our planet an important source of radiation is the sun where, as a result of the fusion process, neutrons, photons and charged particles are emitted, the intensity showing a correlation with the solar activity. On earth, cosmic radiation accounts for approximately 10% of the natural radiation dose.

A larger contribution to the natural radiation burden of mankind is made by irradiation by daughter products of the decay of radon, present in changing concentrations in the crust of the earth. Radon gas diffuses from the rocks in the ground to the surface; owing to variations in radon occurrence and in diffusion conditions, considerable geographical differences are registered. But for man, the dose is even more dependent on the habits of individuals; the exposure outside is smaller compared to that inside buildings, and even inside, substantial differences exist. The radon problem was the subject of a special issue of the journal 'Health Physics' in 1983 with a number of review articles [29, 63, 65]. Special attention has been given to the rate of air exchange, more specifically, the correlation of radon exposure with the construction of energy-conserving houses [14, 64]. Other important parameters are the height above ground and the construction materials, which both influence the exposure to radon daughters [42]. Other sources of radiation which contribute substantial doses, but to limited groups of people, are the monazite sands in Kerala, India [28], and in Guarrapari, Brasilia [4]. Apart from external radiation sources all creatures are also irradiated by internal sources, with a comparable dose. The exposure is the result of isotopes incorporated in our body such as ^{40}K, ^{14}C, ^{210}Po and some other elements which emit electrons, alpha-particles or gamma-rays [78]. The dose due to internal irradiation is not uniformly distributed throughout the body, owing to selective incorporation by some tissues.

Artificial radiation sources

Since the discovery of X-rays by Conrad-Wilhelm Röntgen in December 1895, generators of ionizing radiation have been sources of both intentional and accidental