A child's guide to radiobiology

The view that radiobiology (made fashionable by the accident at Chernobyl) is unknown territory is belied by the vast literature on the subject. But uncertainties persist.

FEW subjects can have been given as much attention in the past thirty years as that of the biological consequences of radiation. The explanation is simply that governments have felt it necessary to make independent assessments of the consequences for their populations of the bulk production of large amounts of artificial radioactivity, which became a live issue in the late 1950s with the testing of nuclear weapons in the atmosphere. The result is that there is no shortage of information. Public reaction outside the Soviet Union to the consequences of the Chernobyl accident has nevertheless provided further proof that to publish is not necessarily to spread understanding.

That radiation may be damaging has been plain for more than half a century, most vividly by the evidence of the damage accidentally done to occupational groups such as the sad cohort of workers in the US watch-making industry employed to paint the luminous dials of watches and who kept their paint-brushes moist by licking them. In the 1920s, the liability to injury of people working with X rays used for medical diagnosis and therapy was recognized by the fixing of a supposed safety limit for exposure, defined as ten per cent of the dose (in roentgens) required to cause a disorder of the blood-forming process in adults.

Now, as the limits have been steadily reduced for the allowable exposure to radiation for occupational and other groups, there is also a reductionist framework to explain the rationale of the dose-fixing regulations. But that does not mean that the uncertainties have been banished.

The agents of the biological damage are, microscopically, a mixed bag, whose effects are best described in language more familiar in high-energy physics. Charged particles such as alpha-particles are stopped in matter of all kinds, living or dead, by the ionization they cause, although there may be occasional nuclear collisions as well. X rays and more energetic gamma rays are also chiefly sources of ionization. Electrically neutral particles, neutrons for example, interact to a comparatively negligible degree with the electrons in the outer shells of the atoms through which they pass, but are capable of colliding with nuclei, which is the simple reason why neutrons are relatively more damaging, by the yardstick of the amount of energy deposited in irradiated material, than most other kinds of radiation.

Inanimate matter is not permanently damaged by radiation except to the extent that ionization of atoms and molecules may catalyse chemical reactions (which is why radiation may cause organic materials to polymerize) or that atoms may be displaced from their required positions by nuclear collisions (which is why irradiated graphite requires annealing).

Living cells are obviously more vulnerable. The mere deposition of external energy in the form of ion-pairs is an assault that may affect essential processes, killing damaged cells or, alternatively, like nuclear collisions at the wrong places in a vital molecule, causing mutations that, in somatic cells, may lead to cancer and, in germline cells, to genetic defects.

By what yardsticks should the potential of radiation for causing damage be assessed? In an ideal world, there would be two quite different bodies of information: first, a set of what physicists would call cross-sections to determine the chance that the passage of a particle (or photon) would set in train each possible biochemical process; and, second, a body of information about the biological consequences. Instead, there are two largely empirical sets of rules of thumb.

The equivalent of the set of cross-sections is the assumption that the damage done to a tissue by irradiation is proportional to the amount of energy deposited within it, whence the unit called the rad. The different components in a mixed source of radiation are weighted according to their "quality factors" to allow for the biological damage they do, by which process rads are translated into rems (for which the unit is the sievert).

Present practice will probably in due course seem crude. Because cross-sections are functions of energy, one would expect the quality factors of the same particles to be functions of energy as well. This point has emerged from analysis during the past few years of the incidence of genetic defects among the children of the survivors of the two bombs at Hiroshima and Nagasaki. Ultimately, no doubt, there will be different quality factors for the causation of genetic defect, cancer and more acute effects, and new units in which to measure them.

The other side of this coin, the numerical relationship of biological damage to its causes, measured as radiation doses, is inevitably more crude. Part of the trouble is simply biological: a genetic defect may show up as a fetus that dies *in utero*, and the biological consequences may be negligible in a population living within its reproductive potential. That is why the working yardstick since the Second World War has been the assumption that, whatever the quantitative relationships may be, the natural dose of radiation to which we are exposed is, by definition, one with which a species must expect to be able to live.

The assumption is natural but its form has changed. Thirty years ago, cosmic rays were supposed to be the chief source of natural radiation; most of the components of cosmic rays, being fast, penetrate the whole body and deliver a reliably calculable dose of radiation, 0.30 millisieverts a year. The effects of naturally occurring radioactive species such as those of potassium-40, have always been recognized as important, but radon-222 now accounts for as great a general radiation dose as the other two put together. On the average, individual exposure to radiation for people living near sea-level is 2 millisieverts a year.

To use natural exposure as a measure of the risks to which people are artificially exposed, it would clearly be necessary that there would be quantities (not necessarily constants of proportionality) relating damage to dose. But it seems unlikely that simple numbers will ever be found. Different kinds of cancer may be induced by radiation with differing efficacy; some genetic defects may be more likely than others.

Complications such as these already have a bearing on some practical problems, especially where internally ingested radioactivity is involved. Although claims that the rate of genetic malformation among the children of people living near nuclear test sites in the United States, put forward by Dr David Sternglass of the University of Pittsburgh in the 1960s, have been shown to be statistically invalid, there is always a possibility that certain radionuclides may have biological consequences that are systematically underestimated by the measure in rems of the dose they deliver, perhaps because they concentrate in particular places. The difficulty here is that each investigation is a major undertaking, and that there are simply not enough people to go around.

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