The DARI

A unit of measure suitable to the practical appreciation of the effect of low doses of ionizing radiation

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A clearer understanding by a wider public of the health effects of radioactive materials arising in the nuclear industry is essential if the public interest is to be served. Even clear and continuous information provided to the public about radiation dose from industry is inadequate to an intuitive and correct understanding of relative risk— in part because radiation exposure is expressed in units that non-specialists find difficult to comprehend.

We propose the establishment of a unit of irradiation dose to the individual that is equal to that provided to a human being by the naturally occurring radioactivity of human tissue: the "DARI," from the French for "Dose Annuelle due aux Radiations Internes"— annual dose from internal radioactivity.

To the extent of 90%, this radiation is due to potassium 40, of half-life 1.3 billion years, which was present in the cosmic dust from which the Earth was formed about 4.5 billion years ago.

The DARI amounts to less than 10% of the natural radiation to which the body is subject, arising from external irradiation from rocks and from cosmic rays. The use of this unit for expressing the individual's radiation dose from an incident or an accident involving radioactive materials would facilitate a proper judgment of its impact, and would avoid unwarranted concerns.

In the physical sciences an important role is played by units of measure that permit an easy appreciation of the order of magnitude of the items measured.

The metre, the kilogram, and the second were thus adopted in engineering. In fields in which the order of magnitude of the object studied are much smaller or much larger, it has been necessary to introduce auxiliary units adapted to daily practice. It is thus in astronomy or in microscopy, where one uses the light-year, or the angstrom and the nanometer.

Over the last few decades there has been a massive increase in use of ionizing radiation. There has been a corresponding evolution of units for the measurement of the intensity of sources emitting radiation and for evaluating their effect on the human being.

The extreme sensitivity of instruments to measure radioactivity, detecting even the disintegration of a single atom, has led practitioners, in their particular fields, to deal with figures that have a substantial number of zeros. Thus the becquerel (Bq) is the intensity of a source in which one atom on the average disintegrates each second; it is used for weak sources, while the megacurie is often used by an engineer dealing with nuclear wastes— the curie (Ci) being the intensity of a source in which 37 billion atoms disintegrate each second— hence 3.7×10^{10} Bq.

Evaluating the effect of radiation on the human body involves more complex questions. The nature of the ionizing radiation— alpha particles, betas, gammas, heavy ions— makes it necessary

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to take into account the great variation in the deposit of energy along the trajectory of the particle and on its effectiveness in disturbing the genetic material of living cells. The mechanisms involved in these effects are still a matter of debate, and the existence or not of a threshold for harm gives rise to argument.

Current units of irradiation

The accepted units, which are employed by various individuals and groups needing to make decisions regarding the acceptable doses of radiation, both for the public at large and for workers in the field, are based on the energy deposited by the ionizing radiation. But they are hardly helpful in providing an intuitive estimate of the nature and hazards of radiation. In this regard, let us just note that the lethal dose of radiation for a human involves the deposition of energy that raises the temperature of the body by a mere thousandth of a degree.

The gray (Gy) corresponds to the deposition of 1 joule per kg of living tissue. One takes into account the different sensitivity of the various human organs by weighting the deposit of energy by a coefficient of effectiveness, which leads to the definition of the sievert (Sv). Finally, although it is a matter of reasonable agreement that the lethal dose is four or five Sv for a human being, regulatory authorities interpret the available facts on the induction of lethal cancer by low doses of radiation as giving a probability of cancer linear with the dose, without a threshold of harm for a human being. Specifically, that estimate is 0.04 lethal cancers per Sv of whole body irradiation. Such a coefficient permits the prescription of permissible levels of irradiation to have an acceptable risk for the various populations, when weighed against benefits to the economy or to the public health in the use of radiation, for instance for the diagnosis or treatment of disease.

Proposal for a new unit linked to the irradiation of the human body by its own natural radioactivity—the DARI

We suggest an approach that may lead to a more intuitive estimation of the impact of low doses of radiation. The unit that we propose provides a much more immediate idea of the risks run by a given level of irradiation. It is as rigorous as the units used thus far, to which it can be related in a precise fashion. We suggest the "DARI," for "Dose Annuelle due aux Radiations Internes—(annual dose due to internal radiation)". This is close to the irradiation experienced during a single year by an individual, due to the radiation emitted by the radioactive materials present in the human body that have nothing to do with any line of work. The DARI is to be defined as 0.2 millisieverts, precisely, although the annual dose itself is about 10% less.

The two principal radioactive substances that contribute to this internal irradiation are potassium-40 (a natural isotope that is a permanent component of living tissue), and carbon-14 produced in the air by cosmic rays and which is present in all living organisms.

We prefer this standard of internal radiation to one representing the average human irradiation from all natural sources that corresponds to a level about ten times larger than the unit proposed. This total varies too much with geography and altitude to serve as a reasonable standard.

Our interest in a standard such as the DARI arises from the fact that even much weaker irradiations than this internal exposure give rise to futile controversy and can distort crucial choices such as those that concern energy supply for centuries to come.

First we discuss more extensively the origin of this internal irradiation, which will permit us to estimate readily the scale of certain incidents or accidents related to nuclear power.

Natural sources of internal and external irradiation

Our planet was formed by the aggregation of the dust from dead stars. All of the chemical elements that compose the Earth were synthesized through the nuclear reactions that take place throughout the life of such stars. Certain elements are radioactive with a mean life in hundreds of millions or billions of years and are always present.

Uranium, thorium, and potassium play an important role in creating the molten core of the Earth. The energy of their radiations has melted and maintains the molten sphere of iron-nickel, some 3500 km in radius, which constitutes the core of our planet.

These primordial radioactive wastes are present everywhere on Earth. Potassium-40, which is a natural isotope of potassium, has a half-life of 1.3 billion years. It pervades living organisms, and the human body of 70 kg mass is host to about 6000 Bq—i.e., 6000 disintegrations per second.

Uranium is widely distributed on Earth and constitutes about 3 millionths by weight of the Earth's crust. Its presence in rocks contributes a significant portion of the natural irradiation to human beings. It also contributes to this total by the radioactivity of one element in its decay chain— radon-222 (of half life 3.8 days), which is a noble gas emitting alpha particles. Radon is responsible on average for more than half of the natural irradiation of humans; the U.S. government recommends effective ventilation of homes in order to reduce the level of radon from building materials or from seepage from the underlying rock.

Nuclear energy and public health

Uranium has a special importance since the discovery of nuclear energy. By use of uranium fission in a nuclear reactor, as much energy could be extracted from the uranium of any given portion of the Earth's crust as if it were pure coal.

Of course, because of the cost of extraction of uranium from such lean deposits, it is currently obtained from the much smaller deposits of higher grade ore— ranging from 0.1% to 14% uranium by weight. But studies show that it is possible to obtain uranium from seawater (where it constitutes only about 3 billionths by weight) with a cost that is a mere 15 times larger at the moment than that required to obtain uranium from the deposits that now serve to feed nuclear power plants. Uranium from seawater thus gives an affordable and practically unlimited supply of fuel for fission power.

In the future, which in the more or less long term is threatened by the exhaustion of the energy resources based on fossil fuel, it is thus legitimate to consider the major role that can be played by nuclear energy. This is particularly true considering the enhanced greenhouse effect from the carbon liberated to the atmosphere by the normal combustion of coal, oil, or even natural gas. However, the enormous amount of radioactivity produced in the course of releasing energy from fission, raises inevitable questions and anxieties about the danger for our generation and those to come, by the massive deployment of nuclear power.

The degree to which nuclear power is accepted depends upon the resources of the individual countries, but also upon a realistic evaluation of the dangers and problems the various alternative energy sources present to the human species. Decisions are rendered more difficult by the sometimes irrational character of the debates concerning the effects on humans of ionizing radiation of various origins, to which we are exposed, voluntarily or not.

A major problem right now for the nuclear industry is to show that it is capable of caring for radioactive waste from nuclear power plants in a satisfactory fashion for generations to come, and is able practically to eliminate the possibility of a major catastrophe like that at Chernobyl in 1986.

To make a proper judgment of various proposed courses of action, it is helpful to take into account the irradiation to which humans are exposed independently of nuclear energy.

Relative importance of natural sources of irradiation, internal or external

Radiation from internal sources is an absolute floor below which it is impossible to sink. Natural radiation overall, about ten times larger, represents a level to which we should refer to evaluate the limits imposed on exposure from the nuclear industry, and in order to evaluate the seriousness of incidents or accidents. We will now examine several sources contributing to natural radiation, using as the unit of irradiation the sievert or the thousandth of a sievert— millisievert (mSv). Cosmic rays shower the Earth and provoke nuclear reactions in the upper atmosphere, caused by the energetic protons of the cosmic rays. At sea level the cosmic rays contribute an annual irradiation about 0.5 mSv. The intensity increases with altitude, which on average contributes more irradiation in a year to airline crews than is legally permitted for workers in the nuclear industry— 20 mSv per year.

In the atmosphere, cosmic rays transmute nitrogen into radioactive carbon— carbon-14, with a mean life of 5000 years; C-14 is present in the form of carbon dioxide within the atmosphere. Incorporated by plants into their tissues, carbon-14 pervades all living things, and along with potassium-40, present since the beginning of the Earth, contributes the most important and least avoidable part of internal radiation. For a person of 70 kg weight, carbon-14 contributes about 4000 becquerel; together with the 6000 Bq from potassium-40, one has thus an activity of 10,000 Bq in the average human being. Taking into account the relative biological effectiveness of this radiation on different organs, this source of 10,000 Bq contributes about 0.17 mSv per year. Incidentally, it is the same 0.17 mSv per year for a child and for an adult of whatever weight, since it is the energy deposited per kg that is measured by the Sv— 1 joule per kg.

Now we compare this level to the total irradiation experienced by humans from other natural sources, totalling, as indicated, about 2 mSv per year. One needs to take into account the radioactivity of the soil containing more or less radioactive material— notably potassium and uranium. In France itself, there is a variability of a factor 3 from 1 mSv in the environs of Paris to 3 mSv in Brittany. On our planet, there are vast populated regions where the natural radioactivity is much greater. Added to the exposure from rocks, there is the radioactivity due to radon, and the cosmic ray intensity that varies with altitude.

Natural irradiation of the average American citizen, like that of the French, amounts to about 2.5 mSv per year, to which must be added the irradiation due to medical diagnostics— on the order of 1 mSv per year on average. The variation in natural radioactivity within France, about 1 mSv per year, exceeds the limit imposed by the law on the exposure of the civil population by the nuclear industry. At this level, it has not been possible thus far to demonstrate any impact on public health; there is no direct evidence of harm caused by irradiation of this magnitude.

It seems to us instructive to choose as a practical unit of irradiation close to that due to the unavoidable K-40 and C-14 in the body, amounting to 0.17 mSv per year, which is quite uniform among the world's population. We have rounded this to 0.20 mSv per year and called it the DARI, for "Dose Annuelle due aux Radiations Internes (annual dose due to internal radiation)". According to the International Commission on Radiation Protection (ICRP), exposure to a DARI conveys a probability of incurring lethal cancer of ten parts in one million. If a lethal cancer corresponds to 20 years of life shortening, each DARI then costs the individual one hour of life expectancy. This calculation is rejected by some who believe in the existence of a threshold, below which there is no harm from radiation. In either case, one hour is little enough to pay for the gift of a body inherited from the stars and the cosmic rays.

The natural variability from place to place amounts to five DARI or more. Nevertheless, we should not countenance the addition of even one DARI to the individual's radiation burden without considering the benefits to that individual and to society.

Table 1 demonstrates the relative importance of various widespread sources of irradiation.

Table 1. The relative importance of various widespread sources of irradiation

0.1 DARI	Dose received in France on average from the nuclear power industry
5 DARI	The soil in the environs of Paris on average
10 DARI	The soil in Brittany on average
5 DARI	Cosmic rays at sea level (increase of 1 DARI per 50 m at altitude).
5 DARI	Average diagnostic radiography*
5 DARI	Limit established for the irradiation of the public by the nuclear industry.
40 DARI	Single CAT scan
500 DARI	Annual maximum dose, for 5 successive years, for a worker in the nuclear industry.
25,000 DARI	Lethal dose for the average human
300,000 to 500,000 DARI	Dose delivered as local irradiation to treat a cancer.

* The DARI is intended to represent an effective dose. If 2 milligray of gamma radiation is delivered to the left side of the body, the equivalent (and effective) whole-body dose is one millisievert or 5 DARI. According to the linear hypothesis for the effects of low doses of radiation, the same probability of cancer will result as if one millisievert were delivered to the whole body — although any tumour will appear only on the left and not the right side of the body. A similar approach applies to the effect of a small diagnostic dose of radioactive iodine — effects of which would be limited to the thyroid but which could be expressed in equivalent whole-body dose in microsieverts or DARI.

The exposure limit of 500 DARI imposed on a worker in the nuclear industry corresponds to a reduction in life expectancy (500 hours) equal to that produced by the smoking of ten cigarettes per day during that same year.

This risk of cancer to a worker receiving the maximum permitted dose in the nuclear industry should be compared with the occupational risks associated with other industrial or commercial activities. For example, driving an automobile in traffic exposes the driver to carcinogenic exhaust fumes (especially particulate matter) with a greater risk of cancer.

Recently one has seen in France polemics over accidental releases of radiation whose impact is less than one hundredth of a DARI, exposing only a local population to this tiny augmentation in irradiation.

The DARI puts in perspective these polemics, of which the impact on the political scene and in the media is disproportionately large compared with the substance. The debate should centre on the following problems as regards future energy:

- What are the real and comparative hazards of various sources of energy now available to humanity?
- After the exhaustion of the fossil energy supplies, what are the options then?

We are expecting 9 billion humans in the middle of this century, compared with 6 billion at this moment. In the industrialized countries, about 20% of the population die of cancer. Among the sources of cancer about half have been identified as due to life style— tobacco, alcohol, obesity, diet—and seem avoidable. About 2% of cancers are thought to arise from carcinogenic materials used in industry, or from automobile exhaust fumes.

One must be alert to reduce to a minimum all of these hazards—especially the more important ones. Those that are due to radioactivity are among the easiest to measure, and they must be maintained at an acceptable level. A unit of measure which takes into account the unavoidable natural self-irradiation of a human being seems appropriate, bearing in mind that it has not been directly demonstrated to have an effect on health.

According to the severe criteria used by regulatory authorities to evaluate the impact of radiation on public health, the DARI shortens life by about one hour per year. And the French accordingly lose six minutes per year because of their dependence on nuclear power—assuredly less than the hazard of the coal alternative. The table shows, however that there is substantial merit in reducing the exposure to the average individual from diagnostic X-rays, which by the same calculation shortens life by an average of five hours per year.

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