Ionizing-radiation standards for populatio[n]

With nuclear power producing an increasing share of the nation's energy, how should we go about setting realistic standards for environmental radiation protection?

Joseph A. Lieberman

Nuclear power generation currently represents the best hope for meeting America's long-term energy demands. The President, in his June 1971 message to the Congress on energy policy, emphasized the role that nuclear power must play in the future and called for additional funds for the AEC fast-breeder program, the most likely design to fulfill the need.

With this increase in nuclear power generation, what will happen to the level of radiation to which we all be exposed as a result? Some members of the public believe that the current radiation protection guides are already set too high and they are concerned about future levels.

It is with this aspect of the energy program that the new Environmental Protection Agency (see box on page 36) is involved. The Agency is charged with the task of assessing the effects on the environment of different methods of producing energy, including of course nuclear power generation. The problems I shall be mainly discussing here are: What should be the basis of the methods we use to set ionizing-radiation protection standards, both for individuals and for the population at large, and what factors do we have to keep in mind when assessing the cost of a given reduction in risk and comparing cost-versus-benefit factors for different installations?

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Principles

In setting radiation-protection standards the Environmental Protection Agency will follow, basically, a set of principles originally drawn up by the Federal Radiation Council. They are:

- It is appropriate to set different standards for different classes of sources.
- Exposure to radiation should always be as low as practicable.
- No exposure should be allowed without expectation of benefit.
- We assume for these purposes that all radiation is potentially harmful.
- We will assume, unless it can be proved otherwise, that the biological risk associated with low levels of exposure is proportional to those risks that have been estimated at higher levels.

In connection with the last of these rules, I should point out that the assumption of proportionality is a conservative guideline. By "low levels of exposure" we mean exposures comparable with exposure to natural background radiation (about 130 millirems per person per year), and no adverse effects have been demonstrated at these levels. Proportionality between exposure and risk is recommended by such expert groups as the National Council on Radiation Protection and Measurement, The International Commission on Radiological Protection, the National Academy of Sciences and the former Federal Radiation Council to be a prudent assumption for radiation-control purposes, but not necessarily biologically *valid*. The true risk at low exposure levels is universally agreed to be somewhere between zero and the risk estimated by linear extrapolation from high-exposure effects.

It is well known that the contribution of man-made radiation (other than medical exposures) to the total population dose has been only a small fraction of the contribution from background

Table 1. Radiation exposure in 1970

Source	Average per capita dose (millirems per year)
Natural background	130
Medical diagnostic x ray	90
Weapons-test fallout	5.1
Nuclear power	less than 0.01

Surveillance studies near a nuclear reactor include measurements on local fish and wildlife as well as direct monitoring of the atmospheric and aquatic environment. Here James Adams of Pacific Gas and Electric Co collects oysters near the Homboldt Bay nuclear plant.

exposure

radiation. Table 1 shows the data for 1970, with the average per capita dose to the section of the population that is at risk, estimated in millirems per year. Not only is the dose from man-made (nonmedical) radiation much smaller than that from the natural background; it is even smaller than the normal fluctuations in that background.

Because of the comparisons made in Table 1 we might wonder whether any additional controls are needed beyond those currently in effect. Yet we know that many people are concerned about the expanding nuclear-power industry and all sources of radiation. They want to know how high the totals of these exposures are going, and what is to prevent them from rising steeply to the existing levels set by the former Federal Radiation Council and by non-Government advisory bodies.

Three interrelated limits

At present three distinct but interrelated numerical values set limits on radiation exposure for the protection of the general public.

The first applies to individual cases; the limit for any one person's whole-body exposure is put at 500 millirem per year.

The second limiting value is for use when a group of individuals is at risk and not all the individual exposures can be measured. The whole-body radiation exposure for the average of a suitable sample of the population at risk must be less than 170 millirem per year. This technique relies on the care with which the "suitable sample" is chosen, if the most-exposed individual is to receive not more than three times the average 170 millirem per year (which would bring him up to the 500 millirem-per year "individual case" figure). The Federal Radiation Council, in setting up these limits, did not specify how to pick a "suitable" sample, but we can assume that "suitability" implies a Gaussian distribution of exposures among the members of the sample.

The third limit is based on considerations of population genetics. The per capita dose limitation for the gonads (male and female reproductive organs) is 5 rem in 30 years. It is perhaps interesting, but quite accidental, that 5 rem in 30 years averages out at very close to the 170 millirem per year limit for whole-body exposure. If the 170 millirem per year level (for a population sample) and the 500 millirem per year level (for an individual) are adhered to, it is practically a physical impossibility for any individual to receive the full per capita gonad dose. The 5 rem per 30 years dose has for this reason never been an effective constraint, yet it is most often interpreted, erroneously, as the "speed limit" that the nuclear industry is determined to reach.

Currently the release of radioactive materials to the general environment is controlled on the basis of limiting the exposure (and therefore the risk) to individuals and small population groups. Until now, because of dispersion and dilution of radioactive materials, exposures to the population at large have been so low that further constraints were not considered to be a priority consideration. This condition could continue, but nevertheless we believe that environmental standards should be set for specific classes of sources or individual plants, thus limiting the integrated population exposures and any health risks that might follow. Each class would be limited to a lowest practicable level of radiation hazard—that is, I foresee one set of standards for water-cooled reactors, another for fuel-reprocessing plants, another for fuel fabrication plants, and so on. As technology improves, we can expect these "lowest practicable levels" to be reduced, so that we will be working *down* towards lower doses, rather than *up* towards higher ones.

An example of the reduction of permissible exposures for a specific class of source is provided by the recent (June 1971) proposal by the Atomic Energy Commission, which concerns radioactive effluents from light-water-cooled nuclear power reactors. The proposed regulations would limit the exposure of anyone outside the plant boundary by a factor of 100 or more below the existing Federal Radiation Council levels. This reduction represents a very significant step in the general direction of limiting environmental exposure to the lowest level practicable under current technology.

Man-rems

We believe that a useful way to evaluate health risks associated with different sources of radioactivity, including nuclear power plants, is to apply the concept that the total health impact is proportional to the total man-rems of exposure. The number of man-rems associated with a source of radioactivity is determined by adding the exposures of all individuals to estimate the cumulative exposure received by all of the population that may be exposed. For example, if 1000 people in a community each received one millirem of radiation per year we could quote the exposure as one man-rem per year.

Does the man-rem concept contain any extra information compared with the established practice of quoting radiation exposures to the individual and averaging over the population at risk? For complete specification of exposures we need to know three things:

(1) Maximum exposure to any individual

(2) Average per capita exposure

(3) Size of the population at risk.

Exposures quoted in man-rems therefore represent a combination of (2) and (3), without taking into account the possibility that some section of the population may have been exposed to greater levels than the remainder of the population.

The man-rem concept, we believe, will help the public to understand the health impact associated with different levels of radiation exposure, because it puts the emphasis on the total estimated actual exposure to people rather than, as at present, averaging out the 170-millirem limit across the population at risk. A vivid demonstration of the way health risks are estimated with these units can be obtained from information in International Commission on Radiological Protection reports; for example, the upper limit of the theoretical risk of increase in cancers is estimated as one cancer per 7000 man-rems. (This is merely an estimate that provides some dimensions to the magnitude of the possible risk.)

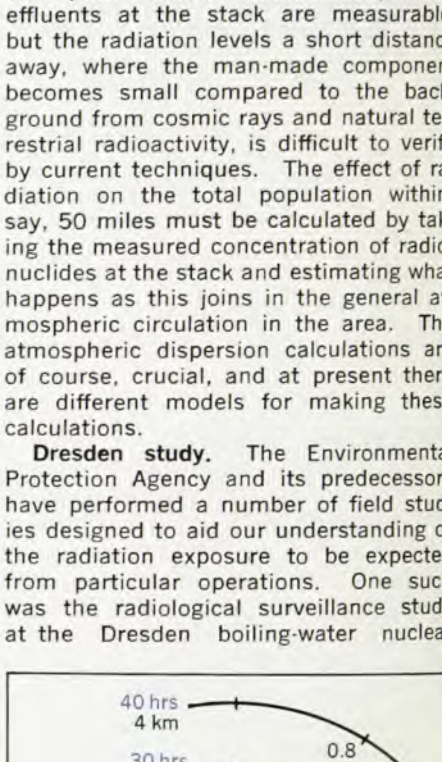
We can compare the health risks from various sources of radiation with each other and with natural background radiation, as we did in Table 1, but in man-rems instead of millirems. Estimates for 1970 and projections for 2000 are shown in Table 2, which gives data

The surveillance problem

Setting radiation exposure standards is only a beginning. To enforce these limits we need some kind of surveillance, so that we can determine what the exposure is at any time and place and compare it with the limit. The trouble is that the environmental exposure to man-made radiation is so much less than natural background (see tables 1 and 2), and variations in the background so comparatively large, that the statistics of any measurement are likely to be poor.

Take for example airborne radionuclides released from the stack of a nuclear power station. Radioactivity in the effluents at the stack are measurable, but the radiation levels a short distance away, where the man-made component becomes small compared to the background from cosmic rays and natural terrestrial radioactivity, is difficult to verify by current techniques. The effect of radiation on the total population within, say, 50 miles must be calculated by taking the measured concentration of radionuclides at the stack and estimating what happens as this joins in the general atmospheric circulation in the area. The atmospheric dispersion calculations are, of course, crucial, and at present there are different models for making these calculations.

Dresden study. The Environmental Protection Agency and its predecessors have performed a number of field studies designed to aid our understanding of the radiation exposure to be expected from particular operations. One such was the radiological surveillance study at the Dresden boiling-water nuclear



"Wind rose" and estimated exposure rates at eleven monitoring stations. Radius of wind rose (color) in any direction shows time (in hours) that the wind blew in that direction. Exposure rates (black) are in μR/hr; numbers in black on the circular grid indicate distance from Dresden.

power reactor in Illinois, 80 km southwest of Chicago. The aim of this study was to "identify and quantify radionuclides in effluents and in the pathways from the point of discharge in the environment to Man."

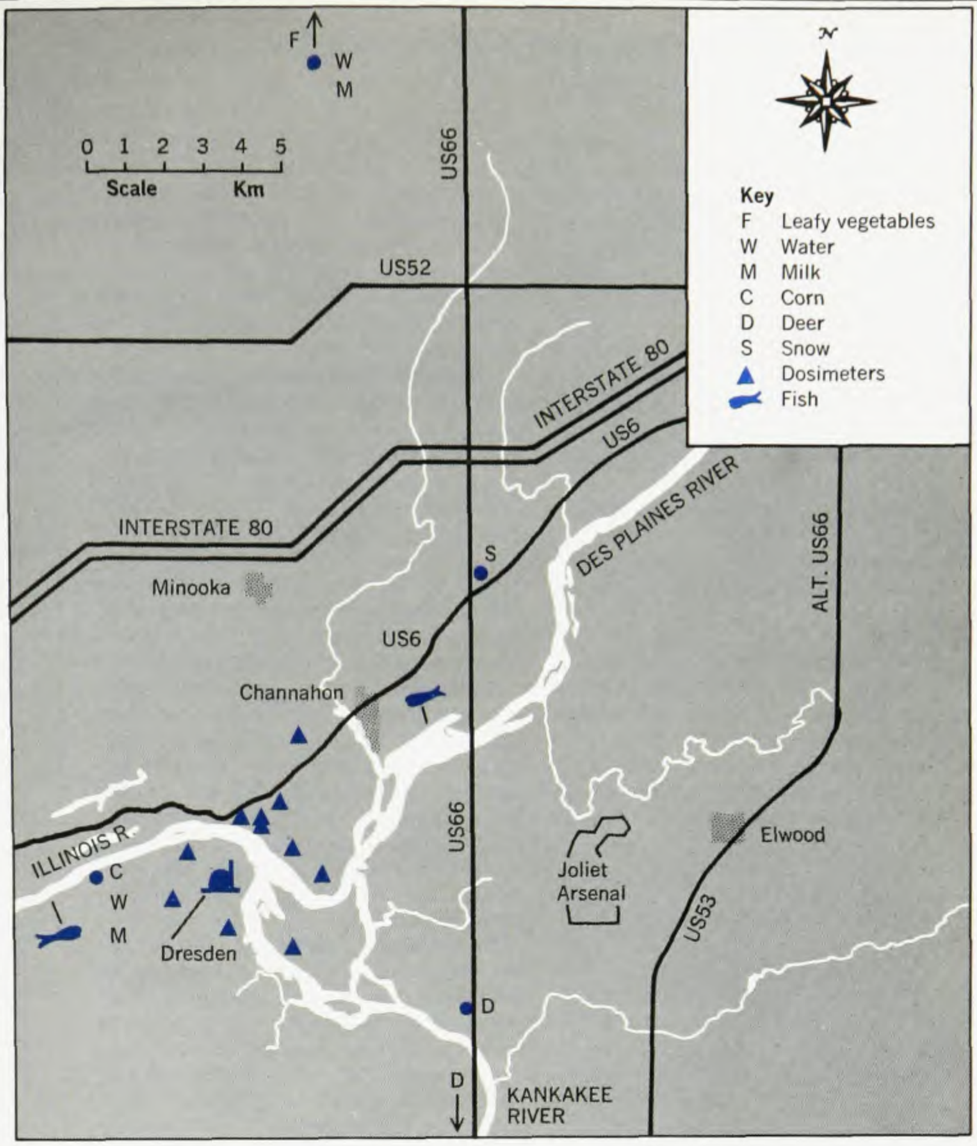
The liquid wastes from this 700 MW (thermal), 210 MW (electrical) reactor go into the Illinois River; gas and airborne particles are released from a 91-meter stack, and solid wastes are buried off-site. Sections of the 116-page report (BRH/DER 70-1) deal with measurements of radionuclides in liquids on-site, in liquid-waste effluents, in the products released from the stack, in environmental air, in surface water and in the "terrestrial environment." Included in the last section are radionuclide measurements of rain and snow, of livestock and feed, of wildlife and of milk. The measurements of surface water included studies of fish samples taken from the river.

Stack effluent. The prominent radionuclides in the stack effluent, as measured by gamma-ray spectral analysis with a Ge(Li) detector, are Kr^{85m}, Kr^{87}, Kr^{88}, Xe^{133}, Xe^{135} and Xe^{138} (see figure below). The radioactivity decreases rapidly with time from its initially measured value; one day after release, only Kr^{88}, Xe^{133m}, Xe^{133} and Xe^{135} could be detected by gamma-ray spectrometry in bottled samples, and after one month only Xe^{133}, Kr^{85} and H^3 remained.

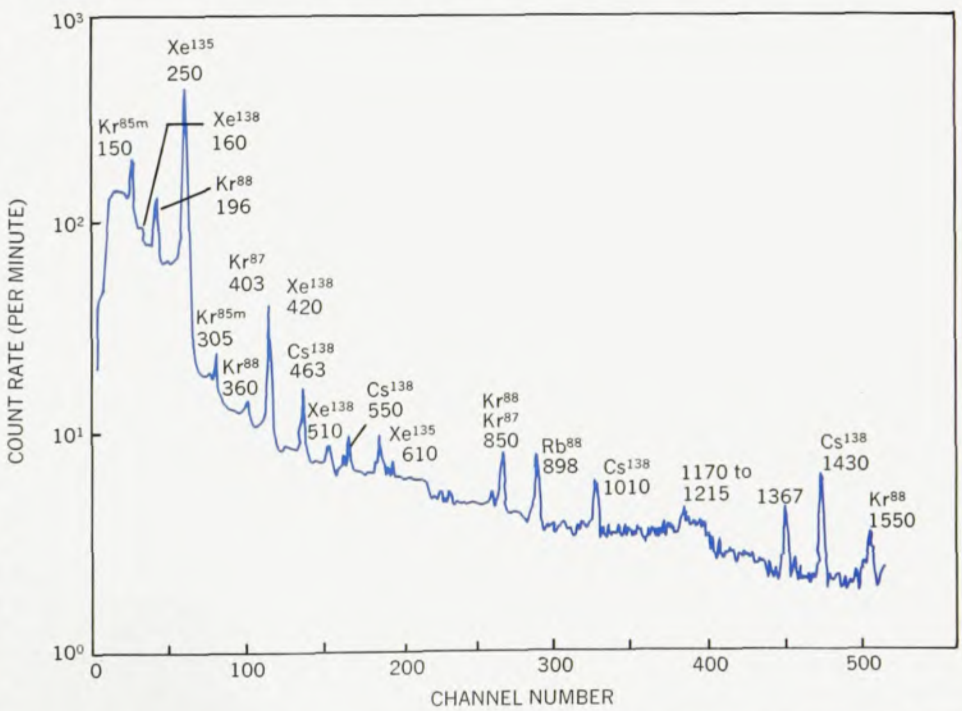
Environmental air. Eleven thermoluminescent dosimeters spaced around the Dresden stack at distances up to about 4 km measured radiation exposure for a total of 12 days while the reactor was operating and 18 days while it was not. A twelfth dosimeter 32 km away monitored general background. The figure (left) shows exposure rates (in μR per hour) measured at the 11 stations and also for comparison the "wind rose"—the time in hours for which the stack effluents were being blown in various compass directions during the tests. The plume could be detected up to about 18 km from the stack with large NaI(Tl) survey instruments.

No radioactivity attributable to Dresden was detected in samples of rainwater, soil, cabbage, grass, cornhusks, milk, deer, rabbit, surface water, drinking water or fish. Some radioactivity from Dresden was found in cattle thyroids, snow, and kernels of field corn collected 0.9 km south of Dresden.

This detailed study, only a fraction of which can be touched on here, is the result of five field trips over a nine-month period. Detailed surveillance, on the other hand, would need similar studies to be carried on continuously at every nuclear installation, which is not an economic possibility. It has been said, indeed, that "routine measurements could cost as much as the reactor does." So there is a need for reliable and accurate mathematical models of the entire environmental system around each nuclear facility, designed to give the same kind of data from simple on-site measurements plus meteorological records. —JTS



Dresden nuclear power station, in Illinois about 80 km southwest of Chicago and 20 km southwest of Joliet, and some of the radiological sampling locations.



Gamma-ray spectrum of a sample taken from the off-gas delay line (one constituent of the stack effluent). Analysis was with a small Ge(Li) detector at Argonne.

The Environmental Protection Agency and its Office of Radiation Programs

On 2 December 1970 the Environmental Protection Agency was established and William D. Ruckelshaus confirmed as its first Administrator. The principal functions of the new agency are:

- To establish and enforce environmental protection standards consistent with national environmental goals
- To conduct research on the effects of pollution and on methods and equipment for controlling it
- To collect surveillance and monitoring data, and to use this information in strengthening environmental protection programs and recommending policy changes
- To work with the Council on Environmental Quality in developing and recommending to the President new policies for the protection of the environment
- To evaluate the environmental impact of Federal activities, as described in the National Environmental Policy Act of 1969. This law requires each Federal agency to prepare a written "environmental impact" statement for each new activity for which it is responsible and which could have a significant effect on the quality of the environment.

Radiation programs are included with pesticides and solid-waste management in the Environmental Protection Agency Office of Categorical Programs, under the direction of David Dominick as Assistant Administrator. The Office of Radiation Programs, of which Joseph Lieberman is head, attends to the protection of Man and his environment from the adverse effects of exposure to both ionizing and nonionizing environmental radiation.

Authorities and resources concerned directly with radiation were transferred to the new agency from three other Federal agencies—the Bureau of Radiological Health of the Department of Health, Education and Welfare, the Federal Radiation Council and the Atomic Energy Commission's division of Radiation Protection Standards.

Scientific and technical support for the radiation programs is provided by field investigations at several operating nuclear facilities. Field projects involving a boiling-water reactor (see box on page 34), a pressurized-water reactor and a fuel-reprocessing plant have been completed. Studies are underway at two other pressurized-water reactors and similar projects are in the planning stages.

in man-rems for the US. The 1970 data for the four broad classes of radiation source are in the same proportion in the two tables, but Table 2 shows that the proportions will change somewhat by the year 2000. Note that exposure to natural background, when expressed in man-rems, will increase during the next 30 years—not because the intensity of background radiation is expected to alter but on account of a growth in the "population at risk" (that is, the entire national population). The figure for weapons-fallout exposure includes a contribution from strontium-90, which accumulates in a person's bones and stays there for as long as he lives. Therefore the estimate for exposure to radiation from fallout in 2000 includes a factor for the intake prior to that year.

At the Environmental Protection Agency we are conducting further analyses, to refine and extend such comparisons. Only by weighing the total impact in this manner can we determine which are the greatest contributors of radiation and estimate the magnitude of the possible effect on the population exposed.

Table 2. Radiation impact on the US, 1970 and 2000

Source	Estimated exposure in 1970 (man-rems)	Estimated exposure in 2000 (man-rems)
Natural background	27 000 000	40 000 000
Medical diagnostic x ray	18 000 000	40 000 000
Weapons-test fallout	1 000 000	1 600 000
Nuclear power	400	56 000

Voluntarily accepted risks

Tables 1 and 2 show that exposure to man-made (nonmedical) radiation for the population as a whole is but a small fraction of background. In fact, far greater risks are accepted voluntarily by those who live in stone houses or at high altitudes; the increase in naturally occurring background to which these people willingly (or unknowingly) expose themselves is itself far greater than the total radiation they receive from nuclear-power sources. For example, how many residents of Colorado realize that they receive three times the annual cosmic-ray dose as do Californians (120 millirems compared with 40) and about twice the annual gamma-ray dose from terrestrial radioactivity (105 millirems in Colorado; 50 in California)? Even if these risks were understood, however, I would presume that few if any people would move from a high altitude or change the type of home they live in for this reason alone.

Exposures from man-made sources of radiation, on the other hand, are not directly under the control of the people who are being exposed. Chauncey Starr, among others, has pointed out that the risks we accept voluntarily are considerably greater than those we accept involuntarily when they result from the actions of others.

The environmental radiation sources are controlled not by the exposed individual but at the source. This is why we can and must look at the total impact to determine how much control is indicated. Just because the risk to the individual is lower than other risks to which he chooses to subject himself does not mean that we have no responsibility for limiting his risk to the lowest level practicable.

At what cost?

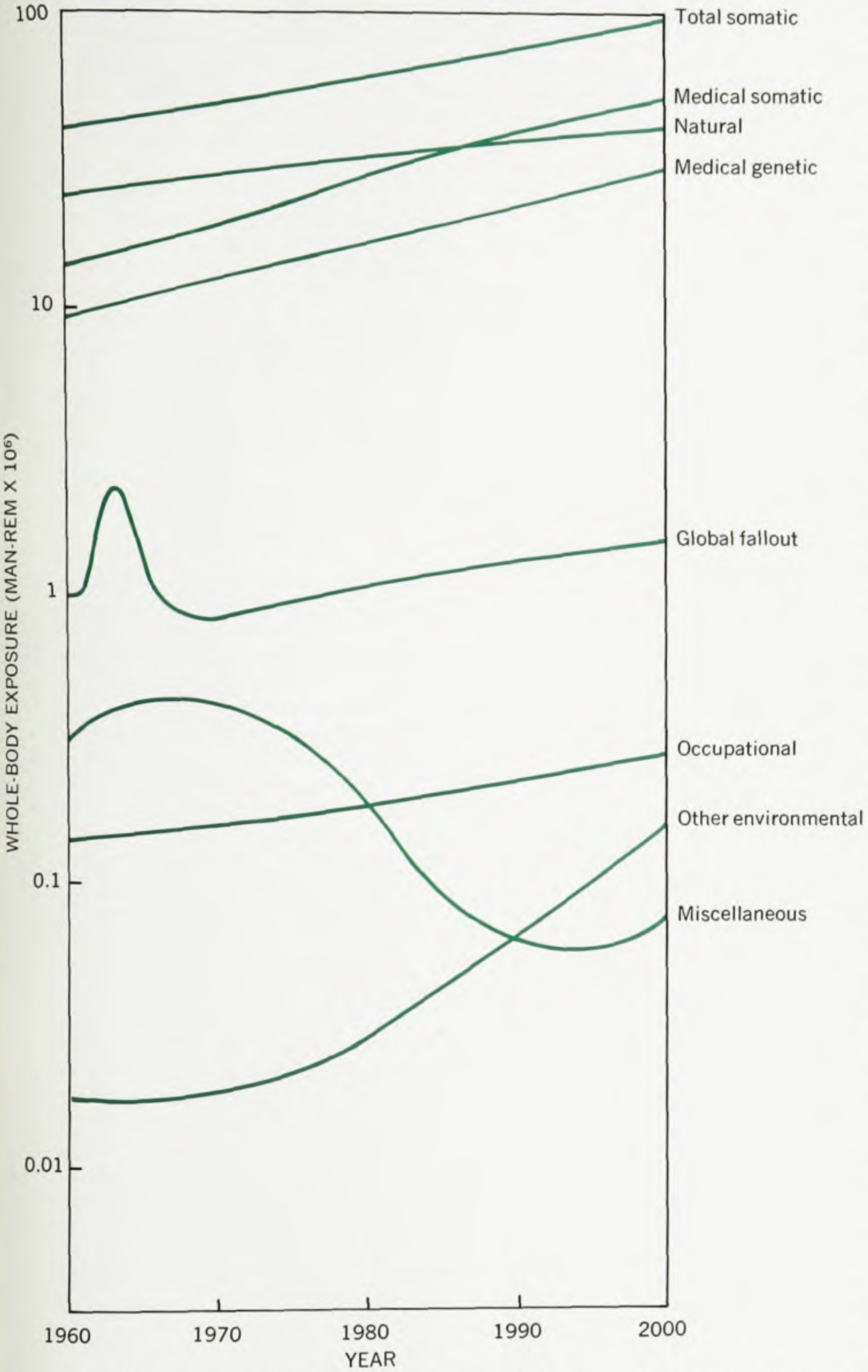
Report no. 9 of the International Commission on Radiological Protection (1965) included this paragraph:

> "When whole populations or large sections of populations are exposed, it becomes necessary to consider not only the magnitude of individual risks but also the numbers of persons exposed. Even when individual exposures are sufficiently low so that the risk to the individual is acceptably small, the sum of these risks, as represented by the total burden arising from the somatic and genetic doses in any population under consideration, may justify the effort required to achieve further limitation of exposure."

The obvious question following upon this statement is: How much effort should be expended to achieve what further limitation of exposure? How many dollars is each man-rem of reduction worth?

Figures for the recommended cost per man-rem reduction have been put forward. Although they are useful as guides, we will need to refine these calculations further before regarding them as wholly accurate.

Before deciding what effort or cost is reasonable we must first estimate the projected exposures and determine the total risk—not just to the individual but also in terms of the total impact on the population. Also we need a good understanding of the control techniques available now and expected in the future, so that we can estimate the cost of reducing these risks. The costs can be in terms of capital equipment, operating costs, possible increased occupational exposure, or potential harm to the environment from alternative programs. We need all this information before we can intelligently determine where and to what extent additional controls might be needed.



Estimated radiation doses in the US, 1960–2000. "Somatic" doses represent radiation that affects the person exposed, whereas "genetic" doses affect only later generations. Natural radiation (cosmic rays and terrestrial radioactivity) and global fallout increase when measured in man-rems solely because of the expected increase in population. The data for "occupational radiation" reflects the increasing industrial uses of ionizing radiation, but the major portion of the dose during 1960–70 is due to medical and dental practice. Radiation from nuclear power plants is included in "other environmental." The "miscellaneous" category covers, for example, television, consumer products and air transport. (Data from the Division of Criteria and Standards, Office of Radiation Programs of the Environmental Protection Agency.)

But before we get to the point of determining where it makes sense to spend money, we first must know that very first part of the equation: What is the total exposure as a measure of risk?

We have the results of calculations that have been made to determine the impact of various classes of source. For example, all the power reactors in the US contributed about 430 man-rems in 1970. However we also need to know the contribution, through all routes of exposure, for each individual plant. We need similar information for other individual classes of nuclear facilities—fuel reprocessing plants, for example—but in most cases we do not have it. Only recently have calculations of this type been made for individual plants.

One duty of the Environmental Protection Agency is to review the statements of environmental impact that are now required under the National Environmental Policy Act. This year we expect to review more than 50 such statements prepared by the AEC for various nuclear facilities—mostly power stations. We have requested that the statements specify the contribution from the release of radioactive gases from power reactors, calculated in terms of the total number of man-rems resulting to the population within 50 miles of the plant.

From the few examples we have received so far it is clear that, because of the variation in population around individual plants, the total integrated dose can differ by as much as a factor of 40 from plant to plant. The obvious question is: If one plant has an impact 40 times greater than another for the same release rate, should the one contributing the higher exposure spend additional money to reduce its effluent?

We are not yet ready to answer that question. First we need to know what the anticipated decrease would be in the total exposure to the population, and we need a better appraisal of the health costs and of the costs of reducing the exposures.

Other consequences

When we measure the impact of radiation on the environment, we cannot ignore the consequences of setting more restrictive environmental standards. One consequence might be an increase in the radiation exposure to workers whose jobs keep them within the plant.

For example, current pressurized-water reactor designs involve the periodic release of portions of the primary coolant to the waste-treatment system, which results in maintaining a low level of tritium in the coolant. If the coolant is all recycled to avoid releasing tritium to the environment, as called for in some new designs, the exposure of maintenance workers may increase as the safety of the general public is improved.

A similar situation may also exist for pressurized-water plants and krypton-85. Recent plans provide a capability for the long half-life krypton-85 to be bottled at the plant and either stored on-site or transported as produced. Here again one must consider whether the incremental reduction in the exposure to the population is justified, taking into account a possible increased risk to the power-plant employees and the economics.

Among other factors that must be considered when setting environmental standards are the siting of the facility, the size of the surrounding population and the potential for exposure in the future.

Longer-range problems have to be included in any assessment of power-reactor impact on the environment. For example, taking the cases of tritium and krypton-85 discussed in the examples above, we may find that low concentrations are not a significant problem either in terms of the dose to the individual near a plant nor for the near-by population. But a greater concern may be the long-term build-up in the environment. In such cases the recommended action may be a limitation on the total quantity released either regionally or nationally.

Aims and perspectives

One important aim of the Environmental Protection Agency is to assess, as objectively as possible, the relative environmental effects of power sources and the appropriate levels of control. This, we hope, will provide an appropriate framework for decisions on these issues by society as a whole.

Radiation hazards exercise the public imagination to a great extent. We want to put radiation in its proper perspective; it is neither a scourge of Mankind, nor something innocuous about which we need not be concerned at all. It is our belief that the nuclear industry can serve the needs of the public without undue risk to our health or to our environment. But we also believe that we have the important responsibility of assuring that this continues to be the case in the future.

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This article is adapted from a talk presented at the 16th Annual Meeting of the Health Physics Society, New York, July 1971. □