termediate in degree of crystallinity. The "razor edge" character of the dimensional change in muscle may thus be explained.

As for a more precise description of how the chemical environment may affect the crystal-liquid equilibrium, we can only surmise that a reagent generated during stimulation, and presumably a product of myosin adenosine triphosphatase activity, is operative in this connection. It may tend to form complexes with functional groups of the protein or to ionize the latter by proton transfer. One may suppose that accommodation of the complex, or of the ionic group plus its gegenion, is sterically difficult, if not impossible, within the crystalline phase, but that no corresponding difficulty arises in the liquid state. The postulated reagent should therefore tend to shift the equilibrium in favor of the amorphous state, thereby promoting shortening. Its dissipation should allow recrystallization during relaxation, and hence a restoration of the initial (rest) length.

The foregoing explanation seems to be free from a number of objections which may be leveled at the current view that dimensional changes in muscle are inspired by alterations of the charge on the protein molecule considered as a random coil polyelectrolyte. The "electrostatic" theory disregards the crystalline morphology of muscle and leads inevitably to the prediction of more or less isotropic changes in dimensions (that is, shrinkage and swelling, rather than contraction and elongation). It offers no satisfactory basis for the peculiar thermoelastic effects observed. Moreover, it is extremely doubtful that the forces generated in tetanic contraction could be held in abeyance by electrostatic repulsions between charges situated on the resting muscle fibril immersed in the sarcoplasmic fluid.

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Pathologic Effects of Atomic Radiation

Appreciation of the pathologic effects of radiation on man has required of this committee and its subcommittees consideration of voluminous experimental work on animals, as well as such direct data on human beings as are available. When the results of controlled experimental studies are considered in the light of the human data, it is found that the sequence of pathological changes is indeed quite similar in man and in animals, although man has certain definable peculiarities of response.

The human data include: (i) results of excessive exposure to x-rays and radium in the early days; (ii) results of more moderate exposure to different forms of radiation, as experienced by cyclotron workers; (iii) results of introduction of naturally occurring radioelements into the body, notably radium preparations and thorotrast; (iv) effects of exposure at Hiroshima and Nagasaki; (v) observations on populations irradiated by fallout; [and] (vi) additional observations from clinical radiotherapy, use of artificial isotopes in therapy, a very limited number of accidents in atomic energy work, and certain statistical surveys of large groups.

Experimental work covers the whole field and includes studies of acute and chronic effects on many species of animals.

Certain human effects have to be assumed from consideration of experimental knowledge—for example, early effects of high doses to the central nervous system and results of absorption of most of the artificially produced isotopes —and it is fair to say that the lethal dosage of penetrating radiation for man is less well known than for many other species.

Radiation has been added to the means

of production of casualties in warfare. Not only can radiation cause death or immediate or delayed injury by itself, but exposure to it intensifies the seriousness of burns or other injuries. The acute lethal dose for half of a given population is in the range of 400 to 600 roentgens.

Despite the existing gaps in our knowledge, it is abundantly clear that radiation is by far the best understood environmental hazard. The increasing contamination of the atmosphere with potential carcinogens and the widespread use of many new and powerful drugs in medicine and chemical agents in industry emphasize the need for vigilance over the entire environment. Only with regard to radiation has there been determination to minimize the risk at any cost.

It appears, however, that a fairly clear general picture of human radiation effects can be presented. Members of this group and of its subpanels, while recommending various points of departure for greater consideration and further research, were in no case of the opinion that any sort of "crash program" would be desirable or profitable.

The various means whereby persons may be overexposed to radiation will have a great deal of influence on the over-all effects. For example, the exposures at Hiroshima and Nagasaki and a few exposures in accidents in atomic energy plants involved radiation to the whole body in which the clinical effects reflected mainly injury to the blood-forming tissues and intestinal tract. These tissues are very sensitive to radiation but have a great power of recovery.

Where, on the other hand, exposure has been suffered at a relatively low level from time to time over a period of years, a variety of injurious effects may be encountered, such as leukemia and skin cancer. Among those who have adhered to present permissible dose levels, none of these effects have been detected.

This article is, with minor changes, the text of the summary report of the Committee on Pathologic Effects of Atomic Radiation. The report is one part of the Study on the Biological Effects of Atomic Radiation conducted by the National Academy of Sciences with the support of the Rockefeller Foundation. The members of the committee are Shields Warren, New England Deaconess Hospital, Boston, Mass., *chairman*; Howard Andrews, National Institutes of Health; Harry Blair, University of Rochester; Austin M. Brues, Argonne National Laboratory; John C. Bugher, Rockefeller Foundation; Eugene P. Cronkite, Brookhaven National Laboratory; Charles E. Dunlap, Tulane University; Jacob Furth, Children's Cancer Research Foundation, Boston; Webb Haymaker, Armed Forces Institute of Pathology; Louis H. Hempelmann, University of Rochester; Samuel P. Hicks, New England Deaconess Hospital; Henry S. Kaplan, Stanford University; Sidney Madden, University of California at Los Angeles; and R. W. Wager, General Electric Company. The last paragraph and the outline of the appendixes to the report have been omitted. The last paragraph states that specific recommendations regarding needed research will be published when the subcommittee reports and other appendixes are published in full. The full report will be published in monograph form by the NAS.

Table 1. Average age at death.

Group	Age (years)
Physicians having no known contact with radiation	65.7
Specialists having some exposure to radiation (dermatologists, urologists, and so forth)	63.3
Radiologists	60.5
United States population over 25 years of age	65.6

Shortening of life span may result from exposure to radiation not only as a consequence of damage to a specific tissue, as seen in the development of skin cancer and leukemia, but also as a result of such general factors as lowered immunity, damage to connective tissue, or premature aging. Older members of the populations seem to be more sensitive to this nonspecific damage. The shortening of life correlates roughly with dose of radiation, but has not yet been demonstrated at low doses. . . . Table 1 indicates life shortening in radiologists, who may well have received doses in the course of their occupation ranging from very slight to about 1000 roentgens.

Shielding of even a portion of the body from radiation lessens the effect out of proportion to the relative amount of tissue protected. Therapeutic radiation to a single portion usually is much greater than the lethal level of total body radiation.

Radiation may have its prominent effects in particular parts of the body when it is applied locally, and this may take place in two ways. First, an external source may be so handled as to direct its radiation to a particular part; in this way many of the early radiologists suffered acute or chronic injury to the hands, which has also occurred in more recent atomic energy accidents.

In the second instance, a radioactive substance may be taken into the body and deposited where it is a source of constant local irradiation until it is eliminated. Bone disease in radium workers and lung disease in miners of radioactive ores (both leading to cancer as a late development) are well-known examples of this mode of exposure. It is worth noting that the atomic energy industry, through diligence, has apparently avoided exposures leading to this type of injury.

It is thus characteristic of the radiations that their effects may manifest themselves not only immediately, but perhaps only after a long period of intermittent radiation, or may even be long delayed after a single exposure. One of the particular tasks of the panel has been to see all of these effects in a common perspective. They are discussed here in terms of the effects of radiation on the important organs and tissues of the body, since it is a well known fact that some are more readily injured by radiation than others, and that injury to some has more serious consequences than to others.

Effect on Organs and Tissues

Among the more serious effects of radiation are those on the blood, since the vital blood-forming organs are particularly sensitive to radiation injury. The white blood cells are decreased in number soon after radiation, and in fatal cases they almost disappear before death. Other acute changes in the blood give rise to disorders in the clotting mechanism and a bleeding tendency, and the formation of antibodies against infections is impaired. These changes lead to acute illness in the second week (perhaps a little later in man), heralded by decrease in the white cells.

In the next few weeks anemias may occur due to deficiencies in red blood-cell formation and survival. Those victims living through the first month usually recover, but in certain individuals, or where radiation is continued, there is a further serious breakdown of blood-cell formation.

Some late effects of radiation appear as leukemias, which are found to arise a few years after radiation. This disease, relatively rare in man, may show manifold increase in persons subjected to a nearly fatal single dose (Hiroshima data) or in those whose professional work has exposed them to higher than acceptable permissible dose rates.

Effects on the intestinal tract are also critical in the early period. Vomiting and diarrhea occur within a few hours. This is a common complication of x-ray treatment to the abdomen, but is not fatal. It seems to be mediated through the vegetative nervous system and is probably not related to later damage.

Within a few days (usually 4 or 5) after radiation, more serious effects occur. Failure of the cells lining the intestine to replace themselves results in denudation of the surface, with intractable loss of fluid and salts, complicated by ulcerations, spread of infection, and bleeding.

Late effects are seen after heavy radiation therapy and resemble those seen in some other heavily irradiated tissues: overgrowth of connective tissue (fibrosis) and decrease in the number of functioning epithelial cells. Cancer has occurred in animals given overwhelmingly large doses of isotopes in insoluble form by mouth.

Effects of radiation on skin have been widely observed. On the first day an erythema, resmbling that of sunburn, appears but is transitory. A few days later a somewhat more persistent erythema occurs which may be associated with pigmentation. Ulceration may occur in this period after high doses. Much later, atrophic changes are seen, with marked deficiency of the blood supply and intractable ulceration; such a chronically damaged skin is a fertile bed for cancer development. The Marshall Island group, while receiving total body radiation insufficient to produce serious changes, had rather marked secondary skin lesions from direct contact with fallout material. Slight local vascular changes have been observed after 2 years, but serious aftereffects are not anticipated. Falling of hair was temporary in these persons; heavy dosages are required to make it permanent. In animals, destruction of the pigment cells causes regrown hair to be white, but such loss of pigment seems not to take place in men under comparable conditions.

Bone: Early radiation effects are not of note, except that retardation of growth of epiphyses of immature bones occurs and may produce serious results in children given local radiation therapy. Late effects are seen in radium poisoning, where we see repeated destruction and repair, culminating in widespread destructive changes in which bone sarcoma is likely to appear.

Lung: Early after large doses we see congestion and increased secretion. Here, again, the late-appearing changes are of greatest importance: fibrosis, and development of cancer, which has been very common in mining areas where large concentrations of radon gas were inhaled.

Thyroid: An early and persistent effect is depression in secretory activity, which is used as the basis of the radioiodine therapy of hyperthyroidism. No serious late local effects of thyroid radiation in adults have been recorded, although some leukemias have followed heavy radioiodine treatment. A small proportion of children treated with x-ray to the upper part of the body, however, develop thyroid cancer later on, suggesting an especially high sensitivity of the child's thyroid.

Eye: The only noteworthy lesion is cataract of the lens, which is a late response. It is much more readily produced by neutrons than by x-rays [and] therefore has been most prominently observed in cyclotron workers.

Gonads: A single sublethal radiation dose to a male may result in sterility after 2 to 3 weeks, followed by a slow recovery. Chronic treatment results in a gradual reduction in number, motility, and viability of sperm. This is the most sensitive indicator of chronic damage so far observed, being measurable in dogs at 10 times the permissible dose rate. Larger doses (about equal to the total-body lethal dose) permanently sterilize males and females. Experience with the Marshall Islanders, the exposed Japanese, and certain accident cases indicate that total body doses up to about 40 to 50 percent of the lethal one have no permanent effect on human fertility.

Central nervous system: observations in man are quite limited. Very high doses given to animals result in loss of coordination and excitement soon after irradiation. At later stages, various effects are seen which indicate sensitivity of particular cells and areas.

Effects on embryos: treatment of embryos at various stages of development may lead to highly specific malformations depending on the exact developmental stage at the time of irradiation. At critical stages, relatively low dosages (those permitting survival of the mother) may cause serious malformations. These changes must be distinguished from genetic mutations, as one is often tempted to call abnormal offspring mutations. The type of malformation discussed here would not perpetuate itself genetically but would result from radiation during gestation.

It must also be remembered that there are various other agents causing malformations during development, of which German measles is a well-known example.

Factors Influencing Sensitivity

A few factors influencing sensitivity might be mentioned. Very young or very old animals have increased sensitivity to lethal effects. Growing tissues are generally more readily damaged. States like hibernation delay the appearance of radiation damage but do not prevent it. Moderate stresses do not seem to effect sensitivity, but severe ones such as burns or exhausting exercise have a deleterious influence, augmenting sensitivity.

Local radiation in sufficient amount to almost any part of the body may produce cancer, the chance of tumor development being somewhat related to dose. Since the cancer cell is an altered type of a normal tissue cell, it has often been suggested that cancer is a somatic mutation, like a genetic mutation but arising in a tissue cell which perpetuates the character by its growth.

All types of induced and spontaneous tumors appear not to arise at once, but to pass through a series of preliminary stages; and radiation-induced tumors take a particularly long time to develop. Radiation-induced cancer occurs in the absence of a generally abnormal state of the tissue of origin. Mouse experiments show that shielding of a part of the body will prevent radiation leukemia and that shielding of one ovary will prevent a tumor from developing in the other; and several of the tumors appearing late after irradiation seem to be produced in response to indirect mechanisms. If somatic mutation is a necessary part of the induction of cancer, it would seem to play a minor role.

Small Dosages and Large Populations

We have so far considered effects of overdosage of radiation in various forms. The question must necessarily be considered whether much smaller amounts of radiation, harmless to individuals, might be deleterious to large populations. Because of the striking difference between germinal and somatic cells, the former carrying on from generation to generation injuries received, the genetics committee has recommended for large populations permissible dose levels of radiation lower than those which are safe for any one generation. If the permissible dose level which they have hypothesized as desirable for large populations were to be applied, there would be no demonstrable somatic effect, although a theoretical minor shortening of life span could not be ruled out.

With regard to internal contamination, independent data on Rongelap inhabitants and Japanese fishermen indicate that a considerable proportion of the lethal dose of external radiation was received by individuals who barely exceeded, and only for a short period, the permissible internal burden.

The only situation worth considering in relation to large-scale pathologic effects would then be widespread contamination with strontium-90, which is a long-lived (half-life 10,000 days) readily absorbed, bone-seeking isotope which tends to fall out generally over the earth rather than in accordance with the usual close or intermediate fallout pattern. It has already been found that some young individuals have retained 0.001 microcuries or one-thousandth of the permissible dose. This amount if maintained through life would yield 0.2 rep (equivalent roentgen) to the skeleton.

In developing an unequivocally safe amount, we can recall that a certain degree of radiation exposure has always been with us, even excluding x-rays, in the form of gamma radiation from minerals, cosmic rays, and radioelements normally in the body. These levels vary greatly from one location or altitude to another and are not considered to produce harmful effects.

There seems no reason to hesitate to allow a universal human strontium (very similar chemically to calcium) burden of one-tenth of the permissible, yielding 20 rep in a lifetime, since this dose falls close to the range of values for natural radiation background. Visible changes in the skeleton have been reported only after hundreds of rep were accumulated and tumors only after 1500 or more [were accumulated].

In relation to world-wide contamination, food chains are important. Fallout contaminates plants through ground and leaf deposition; animals eat these plants. Therefore, milk and cheese are human sources of radiostrontium, being high in calcium. Throughout this chain, strontium is discriminated against relative to calcium, which reduces the hazard somewhat. It must be remembered that in regions where soil and water are low in calcium, calcium and strontium will be more readily taken up.

Therapy of radiation injury: while treatment is difficult, some success has been achieved with antibiotics and properly timed blood transfusions. Shielding of a portion of the body appears to give a degree of protection disproportionately large for the mass shielded. Experiments set up to explain this fact may help in developing a rational treatment. Also, various forms of treatment given immediately before radiation have been devised, but do not appear in any sense practical. Studies of this sort may, however, provide a basis for future discoveries. . . .

Agriculture, Food Supplies, and Atomic Radiation

The committee interpreted its task as requiring its members to survey the scientific aspects of that great sequence of events which precedes the delivery of food items to the ultimate consumer, and to do so from two separate viewpoints. These were (i) the beneficial effects that may result from the deliberate involvement of radiation of any sort with constructive intention, or what has been spoken of so frequently as the "peaceful uses of atomic energy," and (ii) the harmful or disadvantageous effects of radiation of any sort due to nuclear warfare, to accidents involving atomic power plants, or even to a slowly rising background of radiation that conceivably may follow as a result of atomic technological developments in industry.

Public and private funds are currently being expended in the United States for research in agriculture and food processing at a rate in the vicinity of $300 million annually. An undeterminable but not insignificant fraction of this considerable body of research involves radiation or radioistotopes. Members of the committee did not believe it to be incumbent upon them to defend or justify, to criticize, or to challenge applications of atomic radiation to agriculture that have been developed or are under discussion. They did not wish to evaluate the programs of particular agencies or groups, but instead with judicial mind to examine the accomplishments and the potentialities, the implications and the limitations of radiation as related to the production and processing of agricultural products.

One broad conclusion is that there is not imminent any drastic change in *agricultural production* as a result of the application of radiation. However, radiation techniques provide new tools for research and may aid agricultural production by improving and enhancing the efficiency of production methods.

The committee is strongly of the view that the applications of radiation will be of far greater immediate consequence to agricultural research than directly to agriculture, and that most of the benefits that may arise to agriculture, as manifest in the availability of an adequate and varied supply of wholesome food for man, wherever he may be, will come as a summation of many improvements, small and large, in materials, in plants and animals, and in the technology of husbandry and processing developed through programs in agriculture and food processing research.

Changes therefore may be expected to come in a series of little steps, none of which in themselves may be of great impact, but which, through the years, are likely to be impressive in their total.

Another broad conclusion is that the slowly rising background of radiation caused by weapons testing in peacetime at the present rate is not likely to impair or interfere with food production. Levels of radiation considered tolerable by man are below those believed to have effects in plants or animals that would place food production in jeopardy. However, the high levels of radiation which might develop in small or large areas as a result of [the use of] atomic or thermonuclear weapons in wartime, or from mishaps with nuclear power plants in peacetime, could have catastrophic effects on agricultural production that might be of long duration, because of injury to personnel and animals, disruption of services, and contamination of soil, vegetation, and water supplies.

Tracer Studies in Agriculture

In the consideration of the beneficial effects of radiation, the committee endeavored, not wholly successfully, to separate in its thinking those benefits that may arise from additions to the pool of basic knowledge about plants and animals and their welfare from those more direct effects that may specifically result from the exposure of plants, animals, or agricultural products to radiation. Tracer studies in the biological sciences have already been enormously fruitful in aiding the elucidation of essential metabolic processes in plants and animals and may be expected to be increasingly so as the number and diversity of such experiments increases. When there is knowledge and understanding of a process, then comes the opportunity to control it for a desired end; in this way the art of agriculture is transformed to the science of agriculture.

The committee endeavored to make the separation mentioned above because

This article is, with some shortening of the subheads, the text of the summary report of the Committee on the Effects of Atomic Radiation on Agriculture and Food Supplies. The report is one part of a study of the Biological Effects of Atomic Radiations conducted by the National Academy of Sciences with the support of the Rockefeller Foundation. The full report will be published in monograph form by the NAS. The committee members are A. G. Norman, University of Michigan, *chairman*; C. L. Comar, Oak Ridge National Laboratory; George W. Irving, Jr., U.S. Department of Agriculture; James H. Jensen, Iowa State College; J. K. Loosli, Cornell University; Roy L. Lovvorn, North Carolina State College; Ralph B. March, University of California, Riverside; George L. McNew, Boyce Thompson Institute for Plant Research; Roy Overstreet, University of California, Berkeley; Kenneth B. Raper, University of Wisconsin; H. A. Rodenhiser, U.S. Department of Agriculture; W. Ralph Singleton, University of Virginia; Ralph G. H. Siu, Office of the Quartermaster General; G. Fred Somers, University of Delaware; and George F. Stewart, University of California, Davis.