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.

of the conviction that there is nothing unique about radioistotopic studies as applied to agricultural research. Tracer techniques, however, frequently permit answers to be obtained to questions which seemed previously unanswerable by conventional experimentation. The involvement of isotopes puts a new dimension into metabolic studies, and areas, formerly dark, may now stand out in relief.

It is worthy of comment that many of the applied problems involved in the arts or technology of agriculture are as susceptible to study by procedures involving radioisotopes as are those more basic questions of plant and animal physiology or nutrition. Excellent examples of this type of employment of isotopes are to be found in work on the placement and recovery of phosphorus fertilizers in soils, the efficiency of various methods of application of insecticides, fungicides, and herbicides, the determination of post-harvest residues of such chemicals, the extent of utilization of feed components by animals, and so forth. It is to be anticipated that there will be greatly increased use of tracer radioisotopes in the solution of such applied problems and that the immediate dividends from such research may be considerable. Further, it is likely that new methods of employing isotopes advantageously will be developed; the ingenuity of investigators in this field should not be underestimated.

Because of the unanimity of their views as to the enormous potentialities of isotope tracers as a research tool in agricultural science and biology generally, the committee gave some consideration to whether there are limitations in facilities for training or funds for specialized equipment for such studies. The consensus seemed to be that motivation for the use of such techniques must come from individual investigators themselves, that the necessary know-how is to be found in almost all research institutions, and that progress in agricultural research is not at the moment limited by inadequacies in dissemination of knowledge and techniques. There was, however, a feeling that much of the graduate training in this field is rather informal, that more universities might consider establishing courses in which the methodology, techniques, and principles of this new and powerful science are expounded, and that there is an additional need for an advanced training program for specialists in radiochemistry and radiobiology who may be developers of new techniques or interpreters of new applications of potential value in agricultural research.

Crop Production

It is abundantly established that mutations can be induced in many plant species by exposure to x-radiation, gamma radiation, and other forms of radiation. The changes which result are possibly due to chromosome deletions or aberrations. There is some difference of opinion whether radiation-induced mutants intentionally obtained are qualitatively identical with those which occur spontaneously from naturally occurring mutagenic agents, but there is no doubt that their frequency is increased. Even so, the mutation rate in most species is still very small, and furthermore most mutations are disadvantageous. The investigator seeking to exploit this phenomenon must expect to have to handle very large populations, and so far he has been able to look only for desirable changes that are reflected in morphology or appearance and therefore can readily be seen, or for changes which can be recognized by some blanket method such as inoculating all irradiated plants with disease organisms in the hope of finding one or more exhibiting resistance to infection.

It is likely that characters at present unrecognized also undergo change and that there are unexplored potentialities for effecting improvement in quality that may alter the demand for the plant, or in physiological properties that may alter the relationships of the plant with its environment.

It would be a mistake to imply that this new development has greatly simplified the tasks of those involved in crop improvement. On the contrary, it has made them more complex, but, by extending the boundaries, offers many new possibilities. It is not to be expected that acceptable new agronomic varieties can be obtained by simple irradiation of present varieties, though this is possible if large enough populations are examined. In general, however, back-crossing and recombination are needed to add the new characteristic to a crop plant acceptable in other repects.

As yet relatively few new varieties of economic plants, developed from radiation-induced mutants, have actually been introduced and widely planted. These, however, do attest to the potentialities of this procedure. Much of the research effort in this field has properly been devoted to the investigation of techniques, to such vital questions as the determination of the particular stage of development at which radiation exposure may be most effective, and to the comparative mutability of crop species. It appears that different species cannot be expected to respond in an identical manner. More perhaps is known about this aspect of corn genetics than of any other major crop plant.

Mutations in microorganisms may similarly be induced by exposure to various types of radiation, though at considerably higher radiation levels than with crop plants. The changes induced have been shown to include the degree of virulence and host range of certain pathogenic fungi. The suggestion has repeatedly been made that the plant pathologist should examine this phenomenon so as to anticipate disease-resistance requirements in a breeding program. As yet, however, there have been no significant results along these lines. Considerable success has been achieved in the development of greatly enhanced antibiotic production by some molds through radiation-induced mutation and selection. Similar genetic changes in the case of other microorganisms have produced information about the likelihood of genetic control of metabolic processes.

There is considerable evidence that bud mutations or somatic mutations can be induced by radiation and that this phenomenon can be exploited in the development of new strains of crop plants that are normally propagated by cuttings and grafting. This may be of special value in the improvement of some such crops, but as yet there have been no striking accomplishments in this direction. Progress in such studies is, however, inevitably slow because of the nature of the materials and the length of time necessary to recognize a desirable change and to produce the stocks necessary for field evaluation.

Since the mutation rate of plants may be enhanced by radiation, presumably there is some possibility of the appearance of undesirable mutants in areas where the background radiation becomes higher than normal for any reason. This may be of some significance in connection with waste-disposal practices or atomic accidents. There is, however, no evidence of such changes in areas containing radioactive springs or ores. This may be due to lack of intensive examination of the vegetation of such areas, and such surveys are to be encouraged. However, the likelihood of appearance of undesirable lines under radiation levels that would be tolerated on other grounds seems small.

There is no evidence that plant growth is stimulated or crop yields increased by exposure to low levels of radiation, despite earlier well-publicized claims to this effect. Radioactive fertilizers, used in a conventional manner, produce yield increments no greater than expected from ordinary fertilizers.

Plants accumulate nutrient elements present in the root zone in solution or absorbed onto soil colloids, but nonnutrient elements are not excluded and may similarly be taken up. The availability of radioisotopes has greatly improved the understanding of plant nutrition and soil-plant relationships and may be expected to aid substantially in the improvement of cultural practices, as indicated earlier.

Through the use of isotopes it has been demonstrated unequivocally that certain elements can enter the plant through the leaves. This is of some consequence in relation to fallout. Radioisotopes of long life or high activity if deposited in fallout from an atomic or thermonuclear incident are likely to be accumulated in crop plants by root uptake from the soil and entry through the foliage. Some of the products deposited may be initially quite insoluble, but may become soluble through weathering. Others, initially soluble, may be irreversibly fixed by many soils in a form not readily available to crops. It appears at present that strontium-90 and iodine-131 are the chief radioactive elements which are of concern in such circumstances. The subsequent use of such crops presents a great diversity of problems depending on the level of radioactivity, its nature, and the specific use of the crop. The committee was interested to learn that the Department of Agriculture is preparing for farmers some informational material relating to these problems.

The committee desires to examine further the available information on the interactions of fallout components with soil, their entry and accumulation in crop plants in order to determine whether there is available the necessary basic information from which appropriate agronomic recommendations could be formulated for agricultural operations in areas that may have undergone any likely level of contamination.

Animal Production

Whereas it appears that crop improvement programs may be considerably aided by the availability of radiation-induced mutants that may have certain desirable characteristics capable of incorporation into an agronomically acceptable variety, currently available evidence does not suggest that a similar approach with animals would be so rewarding. This statement is made not from a belief that farm animals are inherently less responsive to radiation than plants, but because physical differences of size, cost, generation time, and so forth militate against extensive studies with animals and act as obstacles that cannot readily be overcome. Probably only with poultry and to a lesser degree with swine would it be possible to handle large enough populations, and even here, if one extrapolates from the smaller laboratory animals, the chances of improvement seem slim. At present, one such study, with chickens, is known to be underway.

Limited whole-body exposure studies with farm animals have primarily been carried out to investigate physiological and pathological changes, often with the intention of transferring the information by analogy to problems of responses in man. The sequence of changes induced in most farm animals by heavy radiation exposures has been well defined. There are one or two examples, however, of the use of radiation exposure as a research tool for inhibiting certain functions in animals. For example, various functions in the oviduct of poultry can be blocked by proper radiation techniques, thereby permitting a study of the contribution made by the parts of this organ.

Much of the work with radioisotopes in the animal field centers around problems of animal nutrition and metabolism, and substantial progress has been made both in the elucidation of fundamental problems of animal physiology as well as in those of a more applied character, such as the utilization of feed constituents and the incorporation in animal tissues of inorganic constituents of forages. The experimenters in this field at present encounter one serious difficulty, which in the case of the larger farm animals greatly limits the scale of activity. This is the problem of the salvage or disposal of animals after use in experiments involving radioisotopes or radiation exposure. Even in the case of short half-life isotopes and at tracer levels only, the animals cannot be marketed through the usual outlets. This problem is of course much more serious with dairy or beef cattle than with hogs or poultry because the cost to the program is so much greater. Moreover, this limitation tends to restrict undesirably the scale and scope of such experiments, with the result that the conclusions may be less surely established than if the numbers of animals used were larger.

It appeared to the committee, therefore, that essential research on farm animals using radioisotopes or radiation is being discouraged by the high costs involved because animals must be destroyed at the termination of experiments. It recommends that a special committee be appointed to study this problem and to develop procedures and standards that, if followed and enforced, would adequately protect the consumer but permit the marketing of animals that in experimentation have been brought into contact with radioactive substances or exposed to radiation.

The welfare of the livestock population is enhanced if troublesome insect pests can be controlled or eradicated. As mentioned earlier, insecticide studies have been greatly aided by the availability of radioisotopes as tracers, but in addition there may be certain opportunities for control of insect pests by taking advantage of radiation-vulnerable stages in their life cycles. Eradication of the screw-worm fly from the southeastern United States is to be attempted, based on the virtual elimination of this fly from the island of Curaçao by the release of males rendered sterile by radiation exposure. This technique may not be generally applicable to all insect pests.

Radioisotopes in Agricultural Products and Foods

The committee discussed in detail some of the difficult problems that may arise because of the presence of a radioisotope burden in agricultural products and foods higher than that "naturally occurring." The applicable legislation in this area is clouded with uncertainties because the very possibility was not envisaged by those who enacted the laws and defined the responsibilities of the agencies that protect the public food supply. There are no permissible limits for radioisotopes in foods; any burden above the "natural" is regarded as undesirable. The current interpretation of the law places isotopes in the same category as poisonous additives. It is difficult, however, to be wholly consistent in this, inasmuch as the normal radioisotope burden varies considerably in different agricultural products, and in the same product from different locations. Moreover, the testing of atomic and nuclear weapons is placing in soil, water, and air, the world over, radioisotopes not formerly present, though at extremely low levels. The "natural content" of foods now consumed by animals and man is not the same as in the preatomic age. Though extremely small, the increment is measurable and inescapable.

It is to be anticipated that there will be in the years ahead a slowly rising background of radiation manifest in agricultural and food products by the presence of the isotopes of elements not previously found therein or of "unnatural" levels of radioactivity. Atomic warfare might greatly increase the rate of this development. As pointed out earlier in this report, radiostrontium is particularly the element which would cause concern in the latter event. Forage directly contaminated with fallout, if consumed by farm animals soon after deposition, might cause radiation injury from the presence of insoluble radioactive products. Strontium is metabolically similar to calcium and moves into bone and other calcium-accumulating tissues or fluids. Much is known of the relative behaviors of calcium and strontium, but there appears to be no way of wholly preventing strontium retention. There is some evidence that poultry may "decontaminate" or "detoxify" themselves by reason of a continued dilution through transfer to eggshell. In meat animals, certain tissues might be consumable if boned out, but such an expedient would be beyond the ordinary scope of meat inspection. Dairy products would contain radiostrontium for some considerable time after cows had ingested strontium-containing forage. Moreover, all available feeds, in heavily contaminated areas, might contain significant levels of radiostrontium, perhaps for years.

At present it is not possible to say at what level a food, otherwise wholesome, becomes unwholesome or deleterious by reason of the presence of an unnatural burden of radioactivity. There is a great deficiency of requisite data on the long-term biological effects that may follow the ingestion of such foods by animals and man. Situations in which such information might be of great public importance are not inconceivable and possibly inevitable.

The committee therefore urgently recommends that appropriate experimentation be immediately activated to provide specific information about possible total or cumulative biological effects that might follow the ingestion of such foods. It further urges that the planning of such experiments be broadly based and that the development of the experimental designs and details of their subsequent execution be most carefully considered in order that the emerging data will be acceptable as a basis for the crucial decisions that ultimately will have to be taken, and directly of value to the regulatory agencies charged with the protection of the public interest.

Environmental Changes and Ecological Studies

In the decades ahead there is a strong possibility that the general background of radioactivity in agricultural areas will rise. Contributing to this would be fallout, if weapons testing continues, and wastes from nuclear power plants or isotope processing plants. As indicated in the report of another committee, every effort will have to be made to contain radioactive wastes. Atomic warfare or accidents involving nuclear power sources could of course greatly augment the background and pose difficult problems of land use for agricultural purposes. Limited ecological studies are in progress in the vicinity of certain AEC installations, but it may be wise to consider this general problem somewhat more widely and to attempt to establish, through careful sampling, the present background in representative agricultural areas and in their chief crop and livestock products.

Research activities might appropriately be carried out on areas near weapons test sites where substantially greater changes in background would be anticipated. The distribution in the environment, in the soil at various depths, in the vegetation, in the wildlife, in the streams, and so forth would all be pertinent. The rate of accumulation in soil as affected by land use ought to be studied. Forested land, range land, rotation grassland, and plowland, irrigated and nonirrigated, may each present a different situation. It is possible that certain of the state agricultural experiment stations might be in a position to undertake limited surveys of this type on areas likely to be under their control for some considerable time in the future.

The committee recognized clearly that sustained monitoring and ecological research activities of this type are expensive and are not apt to be professionally rewarding to the individuals participating therein because trends and conclusions would emerge only slowly. However, to be able to recognize changes in the levels of radioactivity in the environment and in products removed therefrom, and to follow movements in the system, may well be in the public interest from a long-range viewpoint.

Food Processing

A recent development in food technology, potentially of considerable and possibly of dramatic significance, is the recognition of the fact that radiation can be used as a means of preserving certain foodstuffs or of lengthening shelf life, either unrefrigerated or refrigerated. The radiation source may be gamma rays or high-energy electron beams. No radioactivity is induced in the irradiated material. Feeding experiments to date indicate that foods so irradiated will prove to be suitable and safe for consumption by man. Parasites in meat and meat products can be killed by exposure to penetrating radiation, and undesirable postharvest changes in plant products, such as the sprouting of potatoes, can be delayed.

The prime objective in radiation processing is to destroy microorganisms, or so greatly to reduce the microbial population (radiation pasteurization) that spoilage is long delayed. To accomplish this, very heavy radiation exposures are necessary because microorganisms are much less sensitive to radiation than are animals and higher plants. The food processor is particularly attracted by the fact that the radiation exposure can and should be carried out after packaging.

The acceptability of some radiation-sterilized foods is open to doubt because of the development of off-flavors and changes in odor or in the texture of the tissues. Much of the developmental work in this field, however, has been of a rather empirical nature, and it is possible that through research means may be found to repress some of these undesirable changes.

Although the feasibility of radiation sterilization has been amply demonstrated, the economics of the various processes have not yet been established. This development has largely been financed by the military with the Army Quartermaster Corps as the primary agency involved, but there has been a broad basis of cooperation in industry and elsewhere, with some technical guidance and evaluation by advisory committees of the National Academy of Sciences. Having in mind the magnitude and coherence of the current broad programs in this area, the committee was of the opinion that the potentialities of this use of radiation are being thoroughly explored and that the interests of the food consumer will be adequately protected. At a later date, the committee expects to review particularly the evidence of wholesomeness and acceptability of irradiated foods.

It is commonly said that P. G. Tait laid down the length of a drive on mathematical principles which could not be exceeded, and that his son drove the ball farther. But at that time Tait had not realized the full effect of spin on the ball.—OLIVER LODGE, *in Past Years, an Autobiography. (Young Tait was a golf champion.)*