scientific basis upon which claims of injury can be assessed and equitable decisions can be reached.

The radiation standards themselves, though sufficiently restrictive to protect the public health, have not imposed undue economic penalty on the technology on which it has the greatest impact—nuclear electric power. More-stringent standards, which might have been necessary in the absence of knowledge gained through the research program, could have easily cost electric power consumers an additional $2 billion annually.

It was stated earlier that research can lead to unexpected rewards. For example, research on Parkinson's disease, which originated in nuclear medicine, resulted in the discovery of a treatment that is entirely nonnuclear in nature. But perhaps no more dramatic example of unexpected benefit exists than the insights that have been gained into biological processes as the result of studies of the effects of low radiation doses. Areas that have benefited from the basic work in radiation biology include genetics and human evolution, immunology, causes of and treatment for cancer, and research on aging.

How did these seemingly unrelated benefits come together? It was already known by the early 1960's that healthy cells have ways to repair damage from certain radiations (e.g., ultraviolet). The repair, first demonstrated on exposed bacteria, was soon shown to apply to human cells. By the late 1960's, it was discovered that victims of a rare skin cancer lacked the ability to repair damage to their DNA, the substance that carries genetic information in cells. As scientists observed the effects of DNA damage, not only from a variety of radiations but also from chemical agents, it became more evident that the cell must possess a mechanism for repairing DNA. Subsequent study of the damage and repair mechanisms, and of the structure and alterations of DNA, led to a host of theories on the possible causes of genetic diseases, birth defects, aging, and cancer, as well as advances in immunology and treatment. Much of this research may eventually resolve the question of the existence of a threshold and the ultimate expression of radiation damage.

Synthetic Fuels The enhanced availability and production of domestic fuels, including synthetic fuels, have remained high in national priorities for many years. The health and environmental aspects of these new energy sources, however, have required investigation because synthetic gaseous and liquid fuels have compositions that can be quite different from those of their naturally occurring counterparts. Some organic compounds in these fuels have been linked to cancer, particularly those fuels consisting of single or multiple ring-shaped molecules (cyclic and polycyclic compounds) and including other elements in addition to hydrogen and carbon. This information is needed by those concerned with industrial hygiene and public health as well as those in process development and planning. On the industrial level, early recognition of the nature of potential risks can indicate the necessity for process modifications and controls to avoid premature commitment to fixed design and thus avoid the imposition of cost-ineffective regulatory strategies. The analysis of uncertainties in the knowledge of health and environmental risks also assists in identifying gaps and in ordering research priorities within the Department of Energy.

Several of the methods used to detect and to characterize the toxicities of synthetic-fuel components were developed within the research program of the Office of Health and Environmental Research and are described later. Briefly, a sequential strategy is employed which uses these tests in determining the toxicities of the large numbers of fuel-component samples to be evaluated. Generally the samples are first screened through a series of easily performed cellular bioassay tests to determine whether the compounds will alter or produce toxic effects in living cells. In practical terms, this involves the physical and chemical separation of the sample into component fractions, followed (typically) by a simple laboratory test of their toxicities. On the basis of these tests, chemical fractions that demonstrate high toxicity or biologic activity and potential for human exposure are tested to determine short-term and long-term toxicities in living animals by skin painting, inhalation, or ingestion. The more elaborate studies using laboratory animals are usually undertaken when the rapid, less costly screening tests indicate that there may be a potentially important human health problem. This, briefly, is the multitiered experimental approach in wide use today.

The ultimate objective of this research is to provide sufficient information for estimating the probability of producing a specified number of health effects in a population for a given exposure to the toxic agent. This draws heavily upon risk-analysis techniques, for it involves extrapolation of animal data to estimate implications of risk for humans. If the uncertainties in this process are large, further research is required.

What, then, have been the major accomplishments in this part of the research program? We now know that some of the compounds that could be encountered in synthetic-fuels manufacture are toxic and mutagenic and that they belong to specific groups of chemicals which now have been identified. This has led to a successful search in both industry and government for methods to alter or reduce the concentrations of these compounds wherever they may occur in synfuel processes. The research program has also focused attention on the need to develop additional data on the effects of the specific synfuels pollutants identified to be of primary