to industrial workers and the general public. Such risk analyses have been used in the development of industrial hygiene practices, radiation exposure control guidelines, and regulatory criteria for the location, design, and operation of nuclear facilities. From the collective effort, a new scientific discipline, radiation biology, emerged and revolutionized the study of biological, ecological, and medical systems. Radiation biology has increased our understanding of fundamental processes by enabling greater quantification of results through new instruments and techniques and by applying the multidisciplinary skills of physical and biological scientists to vital questions of health, illness, and life.

Overview Major research and education programs to study radiation and its effects were first undertaken in the 1940's and 1950's. These programs provided systematic assessments of the immediate or genetic effects of various levels and types of radiation on both humans and animals. Most data on radiation risk before this time had been estimated from measures of effects in persons involved in diagnostic and medical X-ray irradiations or from special studies dealing with issues such as the effects of radium ingested by workers painting watch dials. The epidemiological study of the long-term effects on the survivors of Hiroshima and Nagasaki began with the establishment of the Atomic Bomb Casualty Commission, now called the Radiation Effects Research Foundation. Their studies provided initial information on a wide range of doses of ionizing radiation from many radioactive isotopes, including information on those common to the defense and nuclear power industries.

By the 1960's, comparative evaluations of health risks from radionuclides in defense and energy production included studies at each stage of these industries, from mining and production through storage and disposal of nuclear material. Insights gained from these studies permitted the correlation of results from cells, animals, and humans to provide insight into the biological impacts of radiation. Moreover, they provide the scientific information required to establish realistic exposure limits for both nuclear industry workers and the general population.

The primary unresolved issue in human health-effects studies is the effect of long-term exposure to low levels of radiation. Over the next decade the study of health effects will benefit from its first direct information as many of the workers under study complete expected latency periods (time from exposure to possible cancer onset). Any variations from population norms will provide first-hand data for drawing conclusions about radiation effects. Without this confirming evidence, health effects from low-level exposures would continue to be based on indirect information of three kinds: (1) the lack of adverse effects in the workers under study, (2) estimates obtained from the use of animals as substitutes for humans, and (3) data from the studies of Japanese atomic bomb survivors exposed to medium-to-high levels in a single exposure event. Thus, although enough data for positive confirmation may be 10 or more years away, the fact that the estimates have held year after year for the last 35 years has allowed industries involved with radiation to gain increasing confidence in the standards by which they operate.

The next sections will outline the research areas undertaken by OHER in an attempt to gain a working understanding of the potential human health effects from nuclear technologies. The complementary research efforts of radiation biology, epidemiology, and animal studies support the evaluation of public and worker exposure standards. These sections are followed by a sample of the benefits that have accrued from OHER research in human health effects.

Radiation Biology Radiation biology is the study of the effects of radiation on biological systems. The emergence of radiation biology as a major area of scientific research resulted from the establishment of the AEC and its Division of Biology and Medicine (later called the Office of Health and Environmental Research). Large-scale programs designed to examine the biological effects of atomic radiation were initiated at a number of the OHER-supported laboratories, including those at Oak Ridge, Brookhaven, Argonne, Los Alamos, and Hanford Pacific Northwest Laboratory (PNL), as well as within several nongovernment institutions, notably the Universities of California, Rochester, and Utah, and the Lovelace Foundation (Inhalation Toxicology Research Institute). A smaller program of university-based, contract-supported research was also instituted.

Undoubtedly, one of the major impacts on the expansion of biology in the 1950's and 1960's resulted from the close interaction among physicists, engineers, biologists, and physicians at the radiation biology laboratories. Interdisciplinary research and training with added emphasis on quantification were very effective in bringing about rapid advances in both basic and applied aspects of quantitative biology and medicine. The general trend towards quantitative biology can be seen in the increased emphasis placed on physics, chemistry, and physical chemistry content in biology courses taught at the university level. The value of a solid background in physical science to the biological or medical student is now well accepted.

Discoveries within the field of radiation biology have had a major impact in many areas of science: genetics, biophysics, immunology, nucleic acid structure and function, DNA repair, cell biology, and cancer research. Radiation biology research provided the basis for major advances achieved in research related to human health effects, environmental effects, and nuclear medicine, all discussed elsewhere in this report. Some additional examples will serve to illustrate the breadth of impact of