now that no energy source is entirely free of untoward consequences. Since the seventies, the DOE has thus extended its epidemiological studies to gauge the health effects of the energy choices we must make. Subjects have included turn-of-the-century laborers in coal-gasification plants in Japan and England, present-day workers exposed to diesel bus exhaust, and even residents living near high-voltage power lines.

Enter the Animals

Notwithstanding their undeniable value, retrospective epidemiological studies amount to unintended experiments—experiments that often emerge from historical naiveté, the tragedy of war or accident, or natural forces. Better to know the likely effects of toxic agents before humans suffer the consequences. To get at a deeper understanding of radiation's effects, therefore, the AEC supported animal studies in its very first years—studies that were, in fact, a logical continuation of research carried out during the Manhattan Project to protect workers confronting an utterly unexplored frontier of science.

Perhaps the most comprehensive of these investigations was the "internal emitters" program. Using beagles as their subjects, scientists at many universities and national labs sought to understand the health effects of ingested or inhaled radioactive fallout and of radioactivity associated with nuclear power generation and weapons production. For a variety of elements, in a variety of chemical forms, researchers asked, Where does the radioactivity go? How long does it persist in the body? What organs are affected? What are the health consequences? The answers became a landmark database for the establishment of national and international safety standards.

Another tack was taken by William and Liane Russell at the Clinton Laboratories (now Oak Ridge National Laboratory), where they established a mammalian genetics program in 1947. It was there in the early fifties that Liane Russell observed the exquisite vulnerability of the mammalian embryo to radiation, leading to new radiation safety guidelines for women of child-bearing age, and especially for pregnant women. In the sixties and seventies, the Oak Ridge mice were pioneers again, as mouse genetics studies were extended to the chemicals in our daily lives: the components of pharmaceuticals and pesticides, fuels, airborne pollutants, and cigarette smoke. In 1991, in a commemorative volume, the international journal *Mutation Research* lauded William Russell by saying that "no single person has contributed more to the field of mammalian mutagenesis, and thus to genetic risk assessment in man."

A FAMILY AFFAIR At the Clinton Laboratories in 1947, Liane and William Russell established a program that would make notable contributions to mammalian genetics for the next half-century. An assay they developed for quantifying heritable gene mutations in mice remains a standard today for assessing the human risks posed by radiation and toxic chemicals.

1915 Protection standards describing "safe practices" for handling radium and x-ray machines were published in Germany and Sweden.

1927 American geneticist Hermann Joseph Muller found that x-rays greatly increase mutation rates in fruit flies. His work would be rewarded in 1946 with the Nobel Prize for Physiology or Medicine.

1928 An international congress adopted the first widely accepted x-ray protection standard, a monthly dose limit equal to 1/100 of the amount that burns skin.

1946 President Truman directed the National Academy of Sciences to study the long-term effects of radiation on survivors of the atomic bombs. The Atomic Bomb Casualty Commission was created to pursue this effort, supported by funds from the AEC's Division of Biology and Medicine; its work would continue after 1975 within the Radiation Effects Research Foundation.