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# HEALTH AND ENVIRONMENTAL SCIENCE

## A Brief Review


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# I. INTRODUCTION

The detonation of the first atomic bomb heralded the beginning of a new age. Almost everyone agreed that the enormous energy released by the "atomic reaction" would create opportunities and problems far larger than man had faced in previous history. However, few foresaw the explosion of knowledge that would also be part of this new age.

This phenomena brought potential new tools as well as new hazards to society. Each was as varied as the part of society it effected. To the young mother worried about strontium-90 in her child's milk, it was a threat. To the women with cancer, it was hope. To the doctor, it was a light with which he can look into the human body and spot potential problems. To the engineer, it was unlimited power. To the geochemist, it was a tool for unraveling the secrets of nature. To the peace group, it was the possibility of world destruction. To those charged with defending our country, it was the only means of maintaining a balance of power. And, to the ecologist, it was the means of finally understanding the complexities of the environment, the web of life that sustains mankind.

Even before the research leading to the atomic bomb began, it was recognized that radiation and handling of radioactive materials presented risks. Radiation sources such as x-rays, cyclotron-produced isotopes, and natural radioactive isotopes were known to cause cancer and even genetic damage at high exposures. Still unknown was the relationship between the degree of radiation exposure and the resultant damage. Delayed effects were a major concern. Before nuclear energy could be fully employed, a greater understanding of its negative impacts was essential.

Billions of dollars and important social values were at stake. Workers, the public and the environment had to be protected. Recommendations for doing this differed in cost by as much as a factor of 100 and some recommended walking away from this source of energy altogether. The congress and the administration had to make some difficult decisions but the needed information was not available.

To fill this information void, a research program was established. The program was balanced between directed research to resolve specific questions related to protecting workers, the public and the environment and the search for fundamental insights. This is the story of that program, how it addressed major societal issues, what was learned, how good is that knowledge, and what is yet to be learned.

The story covers the origins of health and environmental research; the early problems related to radiation; the mandate to exploit the opportunities of special nuclear properties in medicine; the need for and development of much more precise and rapid means of measurement, and the new challanges brought about by the new energy sources. The story concludes with a summary of the major open scientific issues and an assessment of how difficult will be their resolution.

Also told are illustrations of how new science has formed the basis of important commercial, or medical developments. Several of these provide annual savings to society on the order of a $100 million or more each. With the exception of nuclear medicine these developments or applications were not explicitly sought by the program. The function of the program was and is to develop information crucial to the defense and energy needs of the Nation. Yet, these "spin-

offs" in aggregate provide annual savings to the Government and the public, several times the annual cost of the entire health and environmental research program itself.

## II. ORIGINS OF HEALTH AND ENVIRONMENTAL RESEARCH: PROBLEMS AND OPPORTUNITIES

Over-exposures to natural radioactive elements had occurred before World War II. Radium dial painters, mostly young women in their late teens and early twenties, had ingested some radium by "pointing" their brushes with their lips. By 1930, when this practice had stopped, bone cancers has already appeared in this large group of women. Studies were started on this occupational disease almost immediately. These and similar studies, plus information from those exposed to large doses from x-rays, provided most of the knowledge about radiation effects in humans available in 1942. Some of these studies are still going on today.

Radiologists during the late nineteenth century were initially unaware of the dangers of ionizing radiation. Often they held x-ray film in one hand while adjusting the x-ray mechanism with the other. The exposed hand received large doses causing many burns that refused to heal. Some radiologists were forced to abandon their professions and some died prematurely from cancer.

In the late '20's, Herman Mueller showed that x-rays caused mutations in the fruit fly but the data was not too useful in predicting the effects on man. The information available from these and similar experiences alerted the atomic researchers to the hazards of excessive radiation exposure, but the information was too imprecise to formulate standards in which confidence could be placed.

Forewarned by these early experiences, the management of the early weapons and reactor programs proceeded with considerable caution so that work could go forward without serious risk to the workers. Concern for safety was so complete that part of Seaborg's first spoonful of plutonium was fed to rats, and scientists at the University of Washington were asked to look for radiation effects

on aquatic organisms Columbia River before the Hanford Engineering Works produced its first plutonium.

However, vastly improved dose effects information was needed by those concerned with fallout, by our nuclear navy, and for the new nuclear power industry. The first order of business in post-war biological research was to develop a program to assess the effects of low levels of radiation on both nuclear workers and the general public. This program would conduct research to determine 1) the effects of radiation on man, 2) how radioactivity was cyclied in the environment, 3) the pathways that carried radioactivity back to man, and 4) how to detect and measure radiation exposure.

During the Manhattan project, there was also a concern for the environment. Initially, it was feared that important species of plants or animals could be severely severely damaged or killed. In May of 1943 at the University of Chicago, scientists with the Manhattan Project were concerned that the Hanford production reactors, to be built on the Columbia River, might endanger the salmon and other fish in that large river. They soon awarded a contract with the Applied Fisheries Laboratory of the University of Washington on the "Investigation of the Use of x-rays in the Treatment of Fungoid Diseases in Fishes."

The title was deceiving, the real purpose was to investigate the effect of x-rays on salmon, salmon larvae and eggs. Since x-rays interact with living tissue, just as gamma rays do, the work was expected to help predict what might happen when the first radioactivity entered the Columbia River. Time was short, the first reactor would begin operations in September 1944. Because salmon eggs take 2 to 4 years to grow to adulthood, with most of that time spent at sea away

from the eyes of observers, the fish from the first irradiation in 1943 would not return until 1945, 1946, or 1947, perhaps too late to provide the necessary data.

Salmon, though important, were poor test animals because of their long periods at sea, so in 1944 the work was extended to trout. Trout can be kept in the laboratory under observation constantly. Consequently in 1945, a new laboratory, the Aquatic Biology Laboratory, a part of the Hanford Operations, was opened.

Since there was no aquatic contamination, the aquatic ecologists were not needed for the first three atomic explosions: Almagordo, Hiroshima and Nagasaki. However, they were pressed into service in July, 1946, at Bikini, when a small bomb was detonated about 500 feet over anchored naval ships in Bikini Lagoon. This shot, Project Able of Crossroads was not too interesting for aquatic biologists. The next shot, Project Baker, was. Exploded at middepth in the lagoon, 90 feet down, it caused severe radioactive contamination in the vicinity of the shot.

Scientists from the Manhattan Project were organized to investigate the results of Test Baker and scientists from the University of Washington were called on to do the work. Although they were used to working in the laboratory, were unfamiliar with oceanographic equipment, and their instrumentation was primative, their work showed definitely that marine animals concentrate radioactivity from the water, and can, if eaten, contaminate man. However, when a resurvey was made later, most of the radioactivity was gone, fishes teemed in the clear waters, waters, and sailors swam where a year earlier, a column of intensely radioactive water had been lifted high in the air.

In addition to defining the biological and environmental hazards of the atom for the users of this new source of energy, the research programs helped develop beneficial uses of radiation in medicine, agriculture and basic biological sciences. The first medical use of radiation was for cancer treatment. Radiation therapy and tumor imaging using radiotracers were both important advances. The use of radiotracers in agriculture led to an understanding of the uptake of essential minerals from the soil, and their movement in plants. Studies of the effects of radiation on living cells and molecules provided insights into the mechanisms of many life processes, previously impossible to observe.

The excitement of the times and the flow of money made available by the great promise of nuclear science prompted many scientists to participate in nuclear research. Hundreds of bright new graduate students followed their professors into the new, burgeoning fields and their scientific publications provided solid ground for the rapid growth of knowledge. Radiobiology, radioecology, tracer chemistry and nuclear medicine were born, and oceanography, ecology, geochemistry, glaciology and many other disciplines of science enjoyed their finest hours.

From the beginning, a dual emphasis existed in the way biological nuclear research was done. The research was stimulated by a need for information so that nuclear technology could be safely developed. This was the mission that justified the research. On the other hand, the biological research could, at the same time, provide an understanding of the basic principles underlying the interaction of radiation with living matter. This dual emphasis was of vast importance, because it would make the results of the biological research applicable in other fields and for other pollutants to face the problems that are bound to arise as new energy technologies emerge.

## III. ADDRESSING THE PROBLEMS: BIOLOGY AND ECOLOGY

The process of addressing the issues associated with radiation produced major fundamental advances in the field of biology and ecology. These advances resulted in diverse and wide spread applications and established a foundation upon which the more difficult and expansive issues could be addressed.

### Biology: The Hazards of Radiation to Man

Soon after the war, steps were taken to learn more about the long-term and genetic effects of ionizing radiation. The atomic bombs dropped on Japan had left many irradiated survivors who feared for their health and future. Efforts began to quantify the exposures and to document the resulting effects, but real progress didn't state until 1950 with the establishment of the Atomic Bomb Casualty Commission. The Commission operated under a wing of the National Academy of Science - National Research Council so that its findings would be above suspicion. Financial support came from the U.S. Atomic Energy Commission with Public Health Officers supplied by the U.S. Public Health Service and the Japanese Government. Since 1975, part of the expenses of the epidemiological study have been borne by Japan.

Epidemiological investigations of the radium dial painters were taken over by the program and enlarged. New studies were started on persons in the midwestern U.S. who drank well water containing unusually large amounts of radium were started. These studies were to help define a threshold value for bone-seeking radioisotopes such as radium, which was still unknown.

In Japan, children of the exposed atomic bomb survivors were examined which continues today for evidence of genetic effects. More recently research for point mutations has been carried out. Despite careful studies, no increase in

genetic damage has been found among these children. However, the tests are incomplete, the sensitivity of the tests poor, and the sample too small to conclude that no mutations will be found. The studies did show, however, that the radiation dose required to induce as many mutations as occur naturally is quite large (i.e., over 100 rads).

These studies provide most of the data used to estimate the hazard of radiation in humans. Some additional information is available from human studies in Europe. Ocassionally, some lesser exposures occur to smaller population samples which may be followed to see if radiation effects (chiefly cancer) occur. Additionally, the health records of the many thousands of atomic energy workers exposed to radiation have been examined. Predictions based on the atomic bomb survivor data, indicate that the radiation exposures are too low, and the numbers of workers too small, to expect to see a statistically significant increase in cancers. So far, this expectation appears to be justified.

Nevertheless, many have challenged this conclusion. Whether the atomic bomb survivors are representative of the Japanese population has also been challenged. Even though these challenges come from a small minority of scientific workers who disagree with the BEIR(III) committee, a group set up by the National Academy of Sciences to look at radiation effects, the challenges emphasizes the need for more definitive data.

It seems evident that no consensus on the quantitative hazard from radiation can be achieved based on epidemiological findings. This lack of agreement largely stems from our relative ignorance of the causes and natural history of cancer.

The pathological processes resulting in cancer must be known before the arguments can be resolved. Only then will we be able to predict the sensitivity of people to cancer, whether induced by ionizing radiation, chemical exposure, or some other mechanism.

To understand the need for basic biological research in solving the epidemiology problem just presented, it may help to recall some early history. In the late eighteenth century when vaccinations began in France, a method was needed to calculate the number of people saved from smallpox, if any, by the new vaccinations. Because effects of other factors were often larger than effects of the vaccin, it was impossible to develop reilable statistics. Of the mathematicians who worked on the problem only Daniel Bernoulli came up with a method that offered some hope of success. He assumed the deaths from smallpox were "independent" of other causes of death.

This principle of independence was probably correct in its application to smallpox. However, it may significantly over estimate effects when applied to "low-level" radiation. The issue to be resolved is the life shortening effects of low-level. There are two problems in determing this effort from epidemiological studies. Firstly, the effects that measured in epidemiological studies are the number of cancers. Secondly, in the case of low-level radiation, the effects are often in the "noise (i.e., the variations between sample groups are larger and usually are attributable to other factors)."

Epidemiological studies have provided a sufficient basis for establishing current worker standards with confidence (see the box on page ____); however, reliance on epidemiology alone is statistically unsettling and has not provided public closure

on the low-level radiation issue. Fundamental new insights resulting from experimental biological science have been and will be regained. Because we cannot predict what evidence will resolve the issue, the research effort needs to be broadly based and diverse.

[Box on Epidemiology of Radiation Exposure]

In the mid-1940's, our experimental knowledge of radiation effects on biological material was full of gaps. Since early work was only on fruit flies, a large effort to determine the genetic effects of ionizing radiation in a higher animal, the mouse, was started. This had to be a long-term project with thousands of animals needed for accuracy, because even at abnormally high doses a specific mutation is a rare event. We have learned that, as expected, a given dose causes more mutations in the mouse than in the fruit fly. The dose rate is important because at lower dose rates repair of the mutated gene occurs, that is a certain radiation given slowly induces a fewer mutations than the same dose given quickly. Although, useful biological information has resulted from these studies, there is much more to be learned. For example, it is not yet possible to translate the effects of radiation on individual animals to the effects of mutant genes in a large population of animals. The latter is an inherently much more complex problem but one of equal or greater importance than the problems now being resolved by the genetics studies.

A diverse program to address this problem and to advance general knowledge of genetics was initiated in association with the mammalian program and conducted in a number of university genetics departments to provide breadth and variety as well as in the National Laboratories. Also required was a means to obtain

genetic information much more rapidly than could be obtained from the animal studies. Bruce Ames at Berkeley developed such a method which has had important applications within the program and currently results in major savings in the chemical and pharmacentual industries (see Cellular Bioassay discussion on page _____).

[Box on Cellular Bioassay]

Parallel with this animal studies program was a somewhat smaller but still extensive plant genetics program centered at a different National Laboratory. Like the animal genetics program, this was composed of both goal-directed experiments (the development of agricultually and commercially valuable new plant varieties by irradiation of seeds followed by crossing and selection), and general development of the science.

Because of the equal paucity of knowledge concerning the lethal effects of radiation and perhaps partly because of an early concern about the effects of a nuclear war a large program to measure lethal effects of various types (qualities) of ionizing radiation was put into place. When one reflects about the number of radioactive isotopes that are known and the various energies of alpha, beta, gamma rays and particles that arise from the decay of these isotopes he realizes that complete knowledge of this type will never be attained. Priorities had to be established and experimental work done on the most likely exposures and the potentially most dangerous isotopes. Those who remember well the 1950's and 1960's may recall the succession of isotopes whose names were associated with periods of public concern: Strontium 90, Cesium 137 and Iodine 131. The waves of concern followed closely the development of new knowledge as each isotope came under closer scrutiny.

The research on movements of isotopes from point of origin to their encounter with humans will be discussed under the ecology section of the report. However, among the investigations on biology detailed here the very extensive work on inhalation must be emphasized. This work started in the early forties as a part of an industrial hygiene program. The rise of the atomic industry has increased the need for continued work along this line as a practical matter and has stimulated fundamental work on lung physicology and lung responses to deposition of various substances. This work provided a large stimulus to the development of precise instruments discussed later. In addition, these developments significantly aided the ability to address questions related to other forms of energy.

Numerous feeding experiments to determine the hazards from various isotopes were conducted and some continue although this type of program is now much reduced. A point of great interest has been to design experiments so that animal studies can be linked to human epidemiology, especially with bone-seeking elements such as radium. This permits use to be made of the dial painter data to estimate effect in humans of other bone seekers such as occur among the transuranics, i.e., plutonium and americium as well as others, without human experimentation.

Up to this point emphasis has been placed on practical requirements of the nuclear development program. A basic philosophy developed during the early period was to encourage work that ensured the maximum yield of fundamental knowledge from experiments which had more immediate application as their primary goal. At the same time basic work which clearly related to the solution of practical problems was encouraged by offering support both to major contractors of the

agency and hundreds of universities and colleges. This helped to ensure the long-term interest of many first class scientists and to provide needed continuity in the program.

Early efforts to apply knowledge gained during the highly secret work of the war period resulted in handsome payoffs. Ion exchange methods were developed for separation of fission products. At the end of the war biochemists in this program turned their knowledge towards using these separation methods on biochemical products. This application together with the new availability and techniques for use of radioactive light elements were indespensible for the extremely rapid post war developments in genetics and biochemistry which generally go under the name "molecular biology." The use of these isotopes and the stimulus provided by new and elegant techniques for separation of minute quantities of biological substances coming at about the same time as the elucidation of the structure of the basic genetic material, deoxyribonucleic acid, reoriented and revitalized all of basic biology.

The continuation and expansion of these early efforts created numerous groups working on the advancing front of biological science, often in close contact with chemists and physicists also working at the forefront of knowledge in their specialties. New discoveries relating to the conversion of light energy by photosynthesis were made in several parts of the program. The chemistry of the photosynthesis set in motion by conversion of light energy to chemical energy was quickly worked out with the help of the newly available long-lived isotope, carbon 14. This work resulted in the awarding of a Nobel Prize to Melvin Calvin of the University of California.

The elegant methods introduced for isotope separation were just the beginning of great improvement in techniques for separation worked out for both large and small scale operations. Some of these were later directed toward the separation of ribonucleic acids important in the process of gene expression. Collaborative work with other Federal agencies provided ribonucleic acid to several institutions where further investigations revealed the structures of these compounds and helped advance knowledge which has culminated in the new techniques of gene-splicing and DNA recombination, bases for a rapidly growing industry.

Little was known at the molecular level about any relationship between cancer and the cell nucleus during the early 1940's. The program being reviewed here began with intensive investigations of carcinogenesis by ionizing radiation and at the same time developed knowledge about the interaction of radiation with cell nuclear material as well as with other cell components. Important contributions to the knowledge of cancer causation came from the studies. When the program was broadened from a strictly nuclear context to include other forms of energy little change in the basic components of the program was required. Cancer remains one of the chief concerns related to all sources of energy production whether solar, nuclear, oil, oil shale, coal or coal converted to oil or gas.

## Ecology

The environmental research during the Eniwetok tests of 1948 followed the pattern of the earlier Pacific bomb tests. The results were essentially the same. Radiation damage to marine life was minimal and radioactivity in fish was disapoted rapidly. In a comparison in 1949 with land plants in the Eniwetok area, the fish were found to be much less radioactive.

Hostilities broke out in Korea and subsequent testing activities were largely confined to the Nevada Proving Ground. The first bomb was detonated in January 1951. Within a few years, 23 bombs were exploded in the desert. Teams of scientists from the University of California at Los Angeles (UCLA) were assembled to measure the effects on land plants and animals. Meanwhile, the Pacific test site would lanuish until the first thermonuclear bomb was exploded at Enewitok in November 1951. Americans were more concerned with the fallout from the Nevada tests. Strontium-90, cesium-137, iodine-131, and the grass-cow-milk-human food chain became part of our vocabulary.

Though there was always concern about people eating fish contaminated by radioactivity from the Pacific tests, the fall out from the Nevada test was much closer to home. Therefore, the terrestival research following the Nevada test was focused on atmospheric transport and movement of radionuclides through the food chain to man.

The first panic was over strontium-90. That was superceded by cesium-137, when it was learned that Alaska natives, particularly the Eskimos at Anatuvak Pass, had high levels of cesium-137 from eating caribou meat, a mainstay in their diet. The world was shocked because Alaska was so far from the nuclear tests, and the levels of cesium-137 were so high. It was a quirk in the ecology that led to the abnormal concentrations, and caused officials high up in the Atomic Energy Commission to become acutely aware of ecological problems. For the caribou fed on lichen--a rootless plant that grew on rock, and like a sponge, absorbed fallout from the air, rain and snow.

The next surprise was iodine-131. Even though it only had an 8-day half life, it was traveling from air to grass to cow to milk to human thyroid so rapidly

it was traveling from air to grass to cow to milk to human thyroid so rapidly that it was the major dose to man. Then a U.S. Air Force bomber crashed at Palomares, Spain, spraying plutonium over acres of tomatoes. These incidents demanded a strong program in terrestrial ecology for it was apparent that no matter where fallout landed in the world, it had the propensity to get into man. How radioactivity moved from soil to plant to animal to man became an important question, and ecology became popular. There was a need to know what the eventual dose to man might be if a certain level of radioactivity were introduced to the environment.

Interest in aquatic ecology and marine transport was at a low during the Nevada tests, but that would change. The world will not soon forget the Bravo shot in March of 1954, part of Operation Castle at Bikini. Bravo brought us face to face with the awesome power of a thermonuclear device, 15 megatons, 750 times as big as the atomic bombs first tested 8 years earlier. It was a shot that went astray, and triggered public reaction that led to a great increase in ecological research. Fallout from Bravo, carried 100,000 feet into the stratosphere, encountered winds aloft and drifted eastward rather than northward, as predicted. This mishap caused the plume to pass over three islands exposing over 200 Marshallese, 28 American military personnel and, unknown at the time, the Japanese fishing vessel Fururyu Maru. The Marshallese and Americans were quickly evacuated, but the ship, covered with ashes from the blast, spent 2 weeks returning to port, broiling in radioactivity. When it arrived, many of the crewman were sick and before long one would die.

Public reaction was predictable. Fish from the Fukuryu Maru were destroyed, and Japanese consumption of fish dropped sharply as frightened citizens turned away

from seafood. Fishermen could not sell their wares, even though most of it was not contaminated, and fish markets went out of business. Everyone had questions. Where did the radioactivity go in the ocean? Would it kill the fish? Was seafood forever contaminated? Would radioactivity get in the Kuriosho current and bathe Japanese beaches? There was panic in Japan, their scientists had no answers, and the Americans, pitifully few. It was apparent that there was much to learn, and soon.

The Bravo shot caused the first real panic because it forced the evacuation of peoples from their homes (in Rongelap, etc.) and it killed a Japanese fisherman. The test demonstrated that fallout was dangerous, and not as innocuous as some had claimed. There is no question that our inability to predict with any certainty where the radioactivity would eventually go, led to the development of an oceanography program in the AEC. The concern of the Japanese, so dependent upon their harvest from the oceans, pressed our research forward. The first step was taken by the Japanese--a cruise of the research vessel Skunkostu Maru--to see for themselves how contaminated were the seas, and the fish. Their seven-week trip in 1954 took them completely around Bikini and Rongelap, on two sides of Eniwetok, and through the tuna fishing areas. The trip was nearly duplicated in 1955, in Operational Troll, by the Americans. Although traces of radioactivity were scattered nearly everywhere, the Troll report said, "None of the edible portions of fish collected...showed levels that would be of concern." However, so many unknowns came to light that there was no complacecy.

In fact, the unknowns were considered in 1955 by the U.S. National Academy of Sciences, which set up a committee on the "Biological Effects of Atomic Radiation," whose Summary Report appeared in 1956. The second meeting of this committee,

April 13-16, 1956, led to the publication in 1957 of a book, "The Effects of Atomic Radiation on Oceanography and Fisheries." The major unsolved oceanographic questions they identified were: dispersion in the upper mixed layer; circulation in the intermediate and deep layers; exchange between the surface layer and deeper layers, sedimentation processes; effects of the biosphere on the distribution and circulation of elements; uptake and retention of elements by organisms used as food for man; and effects of atomic radiation on populations of marine organisms.

The last three problems, at least, clearly called for help from marine ecologists. And, because of the importance of plankton in transporting materials, ecologists were able to help in the other areas as well. These seven major areas of marine science became the heart of AEC's marine environmental program.

Fortunately, the top scientists involved in the NAS study had, with great foresight, called for a study of fundamental processes rather than the dead-end road of "monitoring." The importance lies in the fact that the processes that move radionuclides through the ocean, into marine food chains, and back to man are the same processes that move DDT, PCB's, energy related pollutants, and all of the toxic substances in the environment that plague man today.

The lessons learned in these pursuits have nnot beem lost. They have provided a fundamental store of knowledge on the transport and transformation ofmaterials in the environment. As seen in the discussion of transport on pages ____, this knowledge is currently being applied to important environmental issues.

[Box on transport: ARAC; Continental Shelf Dynamics, Radiological Issues; Transuranic Cycling]

While it was the fear of fallout that opened the public purse, it was the special characteristics of fallout--its radioactivity--that made the study so productive. Radioactive atoms can be measured with 1,000 to 10,000 times the sensitivity of nonradioactive atoms, so that fallout could be literally followed to the ends of the earth. This made it easy to trace as it moved through Nature's cycles. Each radioactive atom "broadcast" its presence and could be followed with unerring accuracy. Of equal importance, each group of radioisotopes decayed at a known rate. A million atoms of $^{131}I$ would be 500,000 atoms in eight days. The use of this built-in time clock was picked up by scientists to determine the rates at which processes were occurring. For the first time, the speed at which sediments accumulated in the ocean, the age of glaciers and how fast materials are moved through the environment could be measured. Because of fallout, ecology became a mature science of recognized value. The AEC, charged with a responsibility for artificial radionuclides, played a major role in this development through its talented contractors.

Hudson
Box on River Ecology

## IV. EXPLOITING THE OPPORTUNITIES: NUCLEAR MEDICINE

In addressing the health and environmental issues related to radiation, unique skills and disciplines were developed by scientists throughout the program. In recognition of the potential values of these skills, they were asked to exploit these skills and disciplines for purposes other than defence and energy. Several efforts were initiated; the most successful of which was nuclear medicine.

The nuclear medicine story had its origin with the discovery of x-rays in 1895 by Roentgen. Shortly thereafter Becquerel observed and interpreted the radioaction projection of uranium.

[Figure showing early instruments: developed photographic plates spinthariscope, cloud chamber and the gold leaf electroscope.]

In 1973, twelve years, after Rutherford inferred the existence of the nucleus from his famous scattering experiment, Hevesy measured the metabolism (uptake) of lead in plants using radiolead-212. In 1924, antisyphilitic mediocaments in animals were studied by Henesy using radiobismuth-210. Blood speed in suspected heart disease patients was obtained by measuring the time required for radium C solutions to traverse from one arm to the other in the first radioactive tracer clinical studies conducted in the late 1920's by Blumgart.

In this period, there was little understanding of the health impacts of radiation, and dose and safety standards were essentially non-existant. Dose rates were governed by the (limited) detectibility of the available instrumentation. Instrumentation to measure radiation took a step forward with the perfection of the Geiger counter in 1928.

Artificial radioactivity was observed and intepreted in 1934 by the Curies. Fermi discovered the neutron, gamma reaction for generating radionuclides and prepared a radioactive isotope of iodine. In the early 1930's, Lawrence invented the cyclotron, and demonstrated that radionuclides of many elements could be generated readily by bombarding various targets in this machine.

The first use of artificial radioactivity in biomedical research occured in 1935 when Hevesy and Chievity fed phosphorous-32 to rats and studied its turnover in tissues. The first therapeutic use of artificial radioisotopes in man occurred in late 1936 when John Lawrence used phosphorous-32 in the treatment of leukemia. The first radioisotope "tailored" for a specific need, and still is wide use at the present time, is iodine-131, discovered in 1938 by Seaborg and Livingood.

The tools and basic knowledge at the time was abismal. The Geiger counter interaction efficiency usually was much less than one percent, and "tracer" doses of about 500 microcuries of iodine-131 were required for thyroid "uptake" studies. We know today that such a dose provides a total body dose of one rad and a thyroid dose of 750 rads. In the late 1930's, implications of these doses were unknown, allowable limits were high, and many of the original experimenters )such as Curie, Hamilton paid the price by dying of leukemia.

The advent in the 1940's of the nuclear reactor provided an intense and copias source of neturons, radionuclides can be generated in huge quantities and at moderate cost by placing cost by placing elements in the neutron flux.
In August 1946, the first shipment of reactor-produced isotopes for civilian uses (carbon-14 for cancer research) was made from Oak Ridge. In late, 1946,

Seidlin and Marinelli announced the first effective treatment of thyroid cancer using iodine-130 and iodine-131. In 1948, Myers announced the first effective treatment of cancer by external radiation using cobalt-60 as the sources.

In 1946, iodine-125 was discovered by Reid and Reston. Because of its nearly total emissions of x- and gamma-rays, its freedom from beta particles, and its convenient 60-day half-life, it is the most widely used radioisotope today through its vitro application to in-vitro radioimmuno-assay.

At this time radiation effects had not yet been reliably determined. Workers on the Manhattan project, for example, were allowed 100 milli rads per day, seven times current standards. Thousands of Ankylosing spondylitis patients received an average dose to the spinal cord and nerves of 700 rads, and hundreds of rads to other body organs, and many contracted cancers later in life. High rates of thyroid cancer were noted in thousands of infants who received 100 to 400 rads of heck irradiation, over one thousand children who received an average of over 400 rads for an enlarged thyroid gland, and over 10 thousand children who received about an 8 rad scalp irradiation for the treatment of timea capitis. Breast cancer was similarly high in hundreds of women who received over 800 rads while being fluoroscoped during lund collague treatment.

These excess were not stopped by the development of improved instruments, but the instruments were essential to subsequent resolution of that problem. The scintillation detector was developed in 1947 by Kallman and gamma ray detectors were developed in the early 1950's. The first rectilinear scanner, hault by Cassen in 1951 required a long time to develop a complete image. Hal Anger developed a rapid moving camera in 1958 to over come this limitation and to

enable dynamic studies (see discussion on the Anger Camera).

[Box on the Anger Camera.]

In 1950, Perlman discovered iodine-123 in the Lawrence cyclotron. The physical properties of this isotope (no beta particles, 13 hour half-life 159 KeV gamma-ray) are advantageous over those of iodine-131 for most diagnostic applications in nuclear medicine, and are beginning to be realized at present. Also, in the early 1950's, Perlman discovered thallium-201 in spallation products generated by bombarding targets with the Berkeley 184-inch cyclotron. (See the discussion on the aplication of thallium-201 for diagnostic of heart disease.)

[Box on thallium-201 for heart disease.]

In the late 1950's, Yallow and Berson invented radioimmunoassay, a method of assaying compounds accurately in vitro using a radiotracer. Iodine-131 was used initially, and was eventually replaced by iodine-125. Hundreds of millions of these assays are performed annually.

As a result of the AEC health research program on radiation effects, stricter controls were place on radiation workers and patients. Also, as a result of more sensitive detectors, smaller doses of radiotracers were used for diagnostic purposes. Allowable radiation worker doses were decreased to five rads per year. Hearings before the Eighty-Fifth Congress on the effects of radioactive fallout showed the potential for danger and led to the subsequent ban on atmospheric testing. The transition of nuclear medicine from an art to a science was underway.

Since 1960, signal enhancement procedures were increasingly applied to the nuclear medicine imagers to provide sensitive and dynamic imaging of all body organs using a wwide range of gamma-ray emitting isotopes. The Anger Camera with Sodium Iodide (Thallium) scintillators accentuated the significance of such radiosiotopes as iodine-123 and technetium-99M, whose low particulate and gamma-ray emissions are so appropriate for camera use (see the discussion on Technetium-99M for the diagnosis of prostate camera).

[Box on technetium-99m for diagnosis of prostate cancer.]

In the 1970's, Brownell greatly improved his positron emission tomograph device by assembling two planar arrays of a gross of crystals which could be rotated halfway around the subject while feeding the interactions of the pairs of 511-KeV photons with the almost 3,000 coincidence combinations into a computer. This allows much new informations to be obtained in vivo, such as metabolism of radio-traced amino acids in normal and diseased states, metabolism of sugars and sub-stituted sugars in regions of the brain during physiological stimulation and in diseased states, and metabolisms of radiotraced amino acids in the normal and diseased myocardium and pancreas.

[Insert paragraph on current agenda for nuclear medicine.]

## V. REFINING THE TECHNIQUES: INSTRUMENTATION

The success of a research program often depends on the development of new instruments and measurement techniques. Early in the history of science observations depended on the five natural senses. Chemists recorded the color, smell, and taste of the compounds they identified. Biologist cataloged plants and animals by size, shape, and color. However, as scientist by size, shape and color. However, as scientists searched for a deeper understanding to measure things that could not be felt, smelled, tasted, heard, or seen.

Immediately after the establishment of the biological and health programs of AEC, the most important measurements problems were related to the hazard of radiation. Instruments were needed to measure the amount of radiation exposure of nuclear workers and experimental animals. Techniques were needed to evaluate the effect of low levels of radiation on living organisms. Both sides of the exposure-effect research needed the development of new instruments to establish the effect of radiation on man and his environment before the beneficial uses of atomic energy could be developed for civilian uses.

The earliest radiation detectors developed for biological use were scintillation detectors. They used the property of some materials to give off small flashes of light when radiation passed through the material. This light was sensed by very sensitive phtomultiplier tubes and the flashes of light were counted. In the early 1950's the sodium iodide crystal detector was developed. In 1955, the liquid scintillation technique was developed, where the radioactive material was in solution with the scintillating material. These techniques provided the means of measuring low levels of radiation in biological materials, leading to an accurate measuremnt of dose for many biological, environmental and medical studies.

By the early 1960's scintiallation measurements had become standards for measurement of radiation in biological materials in medicine and nuclear workers health protection. The search for more sensitive means for measuring gamma radiation in the environment had led to the development of a series of increasingly sensitive solid state radiation detectors. By 1965, a very sensitive gamma ray spectrometer was developed which measured the energy of the gamma radiation as well as counting the number. This allowed the material emitting the gamma radiation to be identified from the characteristic energy. The gamma ray spectrometer will be used to determine the isotopes present in materials from weapons tests fallout and release from nuclear facilities.

The development of the gamma ray spectrometer led to development of two other techniques which could be used to idnetify materials which did not emit gamma rays. Neutron activation is a technique which changes an element to another element having a characteristic gamma ray by bombarding the atomic with neutrons. It is used to identify pollutants, such as heavy metals, in environmental samples. X-ray disperisive fluorescence devices cause a characteristic X-ray to be emitted frm a sample when the sample is exposed to low energy x-rays. The use of these techniques have very broad application to detection of pollutants in the environment, such as analysis of atmospheric aerosols, analysis of toxic elements in tissue samples, and identification of pollutants in soils.

Techniques to measure the effects of radiation on biological systems (living organisms) developed in parallel with the techniques used to measure radiation. Early effects research looked for visible damage or changes which suggested genetic abnormalities. In the early 1950's research in radiation effects shifted to looking for cellular damage. This damage could be seen under a light microscope, though the observation of energy cells to establish good statistical

relationships at low doses was difficult. In the 1960's this research led to cell bioassays for genetic damages. The most famous of these tests is the Ames test developed at the University of California by Dr. Ames. It uses the change in bacterial cultures to synthesize the amino acid histtiderre, which is caused by a single muttion, as an index of the ability to cause genetic change. This assay has been widely used in the 1970's and 1980's to look for genetic damage from chemicals.

The search for a means of statistically establishing the amount of cellular damage from low levels of radiation was advanced by the invention of flow cytometry in 1965. This technique looks at individual cells which are passed by electronic sensors in a liquid supension. Often the cells are dyed with pigments specific to some abnormality and the portion of the cells fluorescing is automaticity recorded. Techniques like cell bioassays and flow cytometry have developed from research tools to means of determining the potential risk of cancer and genetic damage from radiation and chemicals.

[Centrifuge development in DOE labs]

Medical uses of radiation and instruments necessary to fully exploit this potential expanded rapidly in the 1960's and 1970's after the early users of radiation in medicine which can be traced back to late 19th Century (see proceeding section). Medical uses of radiation can be classed as therapeutic use. of radiation of different types, and diagnostic use of a variety of radioisotopes. Therapeutic use of radiation began in the 1930's. The first therapeutic uses of radiation used isotopes such as phophorus 32 and cobolt 60. By the early 1950's irradiation of patients was done on the Berkeley synchnocyclotron. The use of other types of radiation sources which showed promise of important therapy continued through the 1960's and 1970's. The production of Californium,

a spontaneous neutron emmitter allowed internal exposer of cancers to neutron radiation. This promising new technique is still under evaluation.

The use of radiosotopes for detecting abnormalities in the human body without exporatory operations was developed through the 1940's and 1950's. The success of these efforts depended on the discovery of suitable isotopes and the development of "cameras" which would produce images of the uptake of the isotope by of "cameras" which would produce images of the uptake of the isotope by specific organs. The development of these instruments was described in the proceeding section.

As the pace of instrument development increased in the 1960's, the problems of compatibility between instruments and systems of instruments increase. In the 1970's, the use of "on-line" computer analysis further emphasized the need for standard methods of interfacing instruments into systems which would allow collection of large amounts of information from complex experiments. These needs were met by the Nuclear Instruments Module (NIMS) system and the Computer Automated Measurement and Control (CAMACS) system.

The Nuclear Instrument Module (NIM) system was developed to provide a basis for replaceable plug in instruments which kform modules in power supply/instrument racks. The standardization also included some aspects of signal input and outputs to instruments. A 1968 report of the National Academy of Sciences National Research Council states "...the Nuclear Instruments Module system has revolutionized the manner in which experiments are now performed in nuclear physics." The CAMAC system, developed by Harwell Laboratory, England, uses the NIM system but adds digital signals and bussing, systems communications, interfacting to computers and other processors, and the associated software.

The development and general use of these systems have saved millions of dollars by decreasing the duplication of instruments and the decrease in the labor needed to interface incompatible instruments. The savings in time for development of instruments and instrument systems, which relased research scientists to do their primary work, are probably worth more than the more tangible saving in instrument construction and interfacing.

The invention of new instruments and analytical techniques by the biological and health program shas been prolific by an measure. It has both benefitted from and provided stimulus to the explosion of electronic and information science revolution that will probably be considered the mark of our times. The reason for this success is in the basic structure of the biological and health research in the past few decades. First there was a number ofwell defined program goals which not only attracted monetary support but the talents of top scientists. In addition, these scientists were set towards reaching these goals at decentralized laboratories which had a mix of disciplines designed to meet the final objectives. Biologists could learn from physists and chemists, as they learned about the problems and opportunities in biological research. Their combined assalt on the goals of the programs led to many exciting discoveries and inventions.

The approach to solution of biological and health problems in the new energy technologies has been well served by the stategy and techniques first developed to determine the hazards of radiation. Complex chemical mixtures became an area of vital concern in the 19870's as the nation explored the potential of snythetic fuels from coal. Dosimeters for monitoring exposure to polycyclic aromatic hydrocarbons were developed to meet the needs of industrial hygiene in this new area of energy development. In addition, to monitoring devices,

scientific procedures, such as biodirected chemical analysis, were developed to measure the carcinogenic and mutagenic properties of complex mixture of chemicals derived from coal liquefaction and gasification.

Future evaluation of energy technologies will include the evaluation of their environmental and health consequences. The tools to make these evaluations are instruments and scientific procedures like those developed to evaluate the hazards of radiation and the hazards of the chemicals for coal technologies. Only this kind of evaluation will allow the planned mitization of deleterious effects that will lead to public acceptance and optimal development. The instrument development under past biological, environmental and health research has met these challenges by invention, adaption and improvement of new instruments and techniques. Given adequate resources it will continue to meet these objectives.

## VI. NEW CHALLANGES AND FRESH OPPORTUNITIES

A potential flood of new pollutants, such as the exotic chemicals from oil shale and synthetic oil from coal will be produced in quantity in the next decades. Testing their ability to cause cancer, mutagenic effects, or somatic damage is urgently needed to help guide development of the technologies to minimize health and environmental effects. Now, before the technologies are locked into place and billions invested in production facilities, is when guidance can be most helpful, and the least expensive.

The nuclear power industry is in serious trouble, for many reasons. Public fears of the effects of low levels of radiation, accentuated by the Three-Mile Island accident, seem to grow larger each year. The debate about the low-level effects of radiation will have to be settled, which means continued and innovative research. Nuclear waste disposal is viewed by the public as a nagging problem that has to be solved. Already state legislatures have in some cases forbidden nuclear power construction until this delimma is solved. Sea disposal must be investigated and perhaps developed, because land disposal may be politically unacceptable, even though technically feasible. In the present political climate, it is possible that none of the sovereign 50 states will accept high-level radioactivie wastes within their borders. The processes in the deep ocean need to be investigated carefully by scientists of integrity so that public acceptance would follow if safety could be demonstrated.

The breeder reactor and fusion are possibilities in the next few decades. Their future will surely depend on assurance that their effluents are not a threat to life or to the environment. The effects of tritium, plutonium, magnetic effects and liquid sodium all will be questioned before these new technologies will be permitted to proceed.

Although great strides have been made in understanding the effects of radiation (the National Academy of Sciences referred to radiation as the "best known pollutant in the environment"), society is a long way from closure on how to best use the fission and fusion resources. If the American public steps back from the resources, the pressure on our fossil and other energy options will be intense. As seen in the discussion on Coal Liquefaction and Gasification, the program has provided a scientific basis to address some of the new issues. While this work will result in major savings in the development of the synthetic fuels industry, serious issues remain in all area of the new energy technologies.

[Combined Box on Coal Liquefaction and Gasification]

The debate on acid rain grows more bitter by the hour, fueled by inadequate data. Only when sufficient facts are in hand can the proper decisions be made. Billions of dollars are at stake in plant modifications--precipitaters, scrubbers, fluidized beds, etc.--and the increased cost of low-sulfur coal. Great social disruptions can be expected if eastern high sulfur coal producing areas are forced to close. Questions are myriad. Do precipitators increase acid rain by removing the larger particles that are mostly alkaline and could neutralize the acids? Are precipitators an "expensive fix" to remove the visible particles, while leaving the small particles that go deep into the human lung and cause most of the health problems? What triggers the conversion of sulfur oxides into sulfuric acid? In the manufacturing process, the conversion of $SO_2$ to $SO_3$ and then to sulfuric acid won't proceed without a catalyst. Can the catalyst in Nature be found and neutralized, thus eliminating much of the sulfuric acid in rain?

Many serious scientists are concerned with the buildup of $CO_2$. Year after year, slowly but steadily the $CO_2$ levels in the atmosphere increase. As more and more coal is burned, the production of $CO_2$ will increase markedly. While the $CO_2$ in the atmosphere allows the sunlight to pass through to the earth, the longer wavelength light--infrared or heat radiation--can't escape from the earth because it is blocked by the $CO_2$, which is opaque in the infrared region of the spectrum. Many fear that if the earth warms a few degrees, rainfall patterns will change, vast areas of farmland may become unusuable, the ice caps, containing two-thirds of the worlds fresh water, may melt, flooding most existing large cities on the sea coast. The new areas of open water, in the polar regions, once ice is melted, will probably affect the world's climate, perhaps even bringing on another ice age. What are the world's sinks of $CO_2$? Are the higher levels of nitrate and phosphate from sewage in our rivers increasing the production of plants, thus removing $CO_2$ from the atmosphere at an incrased rate? Can the removal of $CO_2$ in the ocean be speeded by an increase in the production of calcium carbonate by shell-forming organisms? Are vast areas of carbon being deposited in the ocean off the continental shelf? Too little is known to predict the results of the buildup of $CO_2$ with any confidence, but the increase is indisputed and inexorable.

Our environment needs to be looked at in a new way--not as a fragile system, to be protected at any cost, but as an active partner in solving man's waste disposal problems. Clearly the environment has a "carrying capacity," the ability to accept wastes at a certain rate without degrading the environment, or harming man through the food he takes from the environment. For example, everyone would agree that one ounce of coal ash, mixed into the ocean would cause negligible harm. However, a cubic mile of coal ash concentrated in the ocean

could have serious impacts. Somewhere in between there must be a reasonable limit that the ocean could accept that would not cause adverse effects. The bacterial systems in the environment, the plants and animals, all have the potential to remove and detoxify wastes. We must enlist the help of Nature by learning what it can, or cannot, do for us.

The earth is one system, made up of air, land, and water. Man must intelligently select which media--air, land or water--can best process the many energy-related wastes from civilization, with the least damage. Those decisions have not always been made wisely in the past and as a consequence unnecessary impacts on both human health and the environment have been suffered.

The ocean is the key to our future in many ways. It contains manganese modules and polysulfide metals--materials of strategic importance. The heat differential between deep and surface waters near the equator have long been known to be a natural storehouse of energy that can be converted to electricity, hydrogen, or ammonia. The seas contain enought uranium and thorium to fuel our civilization for hundreds of years, and enough hydrogen to carry us nearly forever, if they could be economically extracted. Aqriculture seems capable of out-producing land, if the diseases that come with the crowding of organisms can be eliminated, labor costs reduced, and nutritional diets of sufficiently low costs can be developed. But it is as an efficient, low-cost, trouble-free garbage disposal that the ocean offers the most potential to aid civilization. The many cleansing processes in the ocean that dilute, detoxify and remove pollutants from the water must be tested for their ability to come to the aid of beleagured mankind.

It is man that we must worry about most, particularly the effects of exposure to small traces of pollutants over long periods of time. Can lifetime exposures of indoor pollutants such as radon, formaldehyde, oxides of nitrogen, etc., shorten life? Increase morbidity? Is energy conservation dangerous to your health? Are the new kerosene heaters a health hazard? Is the interior of our homes more dangerous than the outside air? Are the massive funds devoted to cleaning up the outside air attacking the least dangerous part of the problem? Should the big effort go to cleaning up the inside air, where we spend most of our time? Can small, inexpensive instruments, like the smoke detector, be made to inform us of dangerous pollutants in our homes?

New and complicated molecules, many closely related to known carcinogens, can be expected from the new energy technologies. The "fish bowl" conditions under which all parts of Government operates makes any errors an embarrassment, if not a crime. Without answers to the health and safety aspects of the new energy technologies, the was decisions will be difficult to make. If correct decisions are not pursued, public confidence will be eroded. Without public support, our energy goals cannot be met.