Protecting and Improving Health Through The Radiological Sciences

I. Introduction

In recent years, the radiological sciences have exerted an ever-increasing influence on the lives of the American people. In the field of medicine, more than half of the population is subjected each year to radiological study, either through the use of x rays or the administration of radioactive materials during the diagnosis and treatment of their disease. In industry and many other walks of life, radiological methods which protect the people from undue exposure to ionizing radiation have made possible the realization of many of the great benefits of the atomic age.

In the future, the radiological sciences are likely to play an even greater role in society. Markedly expanded medical services, intimately involving radiological methods, are being made available to the public. And, further advances in atomic energy will require the careful evaluation and application of protective measures if these advances are to yield their maximum usefulness.

In view of these circumstances, the National Advisory Committee on Radiation believes it timely that a review of the responsibilities of the Public Health Service in the radiological sciences be undertaken. This is particularly so in view of the recent emergence of a number of problems which if allowed to continue may seriously hamper such programs as Medicare and the nation's efforts to combat cancer, heart disease and stroke. Furthermore, additional problems are making more difficult the translation of the advances of atomic research into needed benefits for the public. In this Report, the Committee has made an effort to identify these problems and to propose a series of recommendations which may be helpful to the Surgeon General in bringing about their early resolution.

II. The Development of the Radiological Sciences—A Short Historical Review

To place the discussions of this Report in perspective, the following history of the growth and development of the radiological sciences has been prepared. Although brief, it provides background information which may assist the reader in gaining a better understanding of the complex interrelationships prevailing in the nation's use and control of ionizing radiation.

The radiological sciences had their origin in November, 1895, when Wilhelm Conrad Röntgen, professor of physics at the University of Würzburg, Germany, discovered "a new kind of rays" which he subsequently called "x-rays". There are few scientific discoveries in the history of mankind that have generated scientific and public reaction so immediate and so great. The possibility of using x-rays in medical and surgical diagnosis was recognized at once. Within the first year after the announcement of the discovery almost one thousand scientific papers and many textbooks on x rays were published. In February of 1896 the Journal of the American Medical Association expressed the cautious opinion that x-rays might be useful in the treatment of disease.

From the early applications of x-rays in medical diagnosis, the branch of the radiological sciences now known as *diagnostic roentgenology developed.* Simultaneously, the use of x-rays in the treatment of disease gave birth to the clinical specialty of *radiation therapy.*

Medicine was, of course, not the only scientific discipline to benefit from Röntgen's discovery. The natural sciences also profited at once. One of the most important consequences was the discovery of radioactivity by Becquerel in 1896, soon to be followed by the discovery of radium by Marie and Pierre Curie in 1898.

The discoveries of Röntgen, Becquerel and the Curies were the forerunners of seven decades of brilliant scientific achievement. In 1905, Einstein proposed that mass and energy are related by the now well-known equation, $E = mc^2$, in which E signifies energy, m mass, and c the velocity of light. In 1911, Rutherford proposed an atomic theory in which he suggested that the mass and positive charge of the atom are concentrated in a central nucleus. And in 1913, Bohr proposed an atomic model comprising a central nucleus with electrons moving in systematic orbits about it. Although modified considerably in later years, this model was of great value in guiding research in the physical sciences at the time.

In 1919, Rutherford found that the nuclei of nitrogen atoms under certain experimental conditions of bombardment yielded positively charged particles which he named protons. He also observed that in this process the nitrogen atoms were transformed into oxygen. This was the first experiment in which one element was artificially transformed into another. In the next year, Rutherford proposed that atomic nuclei also include a fundamental particle approximately the size of the proton but bearing no electrical charge. This particle he named the neutron. Twelve years later, Chadwick discovered the existence of this particle and in 1934, Fermi, while bombarding uranium and other atoms with neutrons, observed many phenomena of artificial transmutation and radioactivity.

Simultaneously with the work in the physical sciences, a number of investigators began to study the biological effects of x rays and of the radiations emitted from radium. Quite accidentally in the early part of this century it was discovered that some physicians who used x rays in the diagnosis of their patients developed inflammatory changes of the skin of their hands, changes which not infrequently became cancerous. These effects were traced to the practice of these physicians of placing their hands under their fluoroscopes each day while they tested the operational characteristics of their equipment.

The damage done to the hands of the pioneer radiologists was due to relatively large doses of x rays. Late in the 1920's Muller discovered that relatively small doses of radiation to reproductive cells produce changes or mutations in succeeding generations of the irradiated species.

Between 1934 and 1940, several hundred artificially created radionuclides were discovered. Use of these materials in medicine led to the birth of the clinical discipline now known as *nuclear medicine.*

In 1939, Hahn and Strassman bombarded uranium-235 with neutrons and demonstrated the phenomenon of nuclear fission, a process in which each uranium atom broke into two approximately equal parts. The process was accompanied by the liberation of neutrons and the release of substantial amounts of energy. Hence, work was begun to devise an experiment in which uranium could be made to undergo fission in a self-maintaining, controlled reaction. In December, 1942, this culminated in the development of the first successful uranium pile or reactor at the University of Chicago.

The work at Chicago raised the curtain on the atomic age. The reactor made possible the production of large amounts of radioactive materials which soon found widespread use in research and development in industry, agriculture and medicine. It ushered in the era of power from nuclear sources. And it made possible the production of atomic weapons of unprecedented magnitude.

After the end of World War II, it was confidently predicted that the enormous advances which had taken place in the natural sciences since Röntgen's discovery would bring untold benefits to all mankind. Spectacular developments in the diagnosis and treatment of disease were anticipated. The provision of unlimited amounts of cheap electric power for every nation in the world seemed possible. And the application of the nuclear sciences to a vast array of industrial and agricultural processes appeared likely to open up a great new period of technological development and economic progress.

For some time, these promises were unrealized; progress was disappointing. However, if an error was made in assessing the impact of the atomic age on society, it was an error of timing rather than of substance. Recently, progress has been accelerating. Nuclear

medicine has reached a stage of development where the number of patients examined by this method is doubling every three to five years. In industry and agriculture, the applications of radioactive materials are expanding rapidly. And nuclear power reactors are being planned at a rate such that one may expect a substantial fraction of the electric power generated in the United States will come from these installations within the next few decades. There can now be no question that atomic development will exert a substantial and continuing influence on society in the years to come.

III. The Developing Role of the Public Health Service in the Uses and Control of Ionizing Radiation

(a) The Scope of the Radiological Sciences

The sum of systematized knowledge pertaining to the application and control of ionizing radiation is the province of the radiological sciences. From a health standpoint, the radiological sciences of greatest interest are those concerned with the uses and control of ionizing radiation in medicine, dentistry and their related disciplines and those pertaining to the control of such radiation in industry, agriculture and the environment. In this report, the radiological sciences, for purposes of discussion, have been divided into the following categories:

I. CLINICAL SCIENCES

1. Diagnostic Roentgenology: the use of x-rays in the diagnosis (recognition and evaluation) of disease.

2. Radiation Therapy: the use of ionizing radiation, including that produced by x-ray machines, particle accelerators and radioactive materials, in the treatment of disease.

3. Nuclear Medicine: the use of radioactive materials in the diagnosis of disease.

By custom, diagnostic roentgenology, radiation therapy and nuclear medicine are often collectively referred to as radiology.

II. COMMUNITY HEALTH SCIENCES (PUBLIC HEALTH DISCIPLINES)

1. Radiological Health: the prevention of undue exposure of the population from ionizing radiation and the use of such radiation in the preservation and betterment of public health.

2. Health Physics: the use of physical methods in the protection of man and his environment from unwarranted radiation exposure.

III. LABORATORY SCIENCES

1. Radiobiology: the study of the biological effects of ionizing radiation and the use of such radiation in the investigation of fundamental biological phenomena.

2. Radiochemistry: the branch of chemistry dealing with radionuclides and their properties, with the use of radionuclides in the study of chemical problems, and with the behavior of minute quantities of radioactive materials detected by means of their radioactivity. Important to medicine are:

(i) clinical applications: the development and production of radionuclide-labelled compounds for pharmaceutical and biochemical use; and

(ii) analytical applications: the assay by chemical processes of the radioactive constituents of compounds and contaminants.

3. Radiological Engineering: the design, development and utilization of radiological instruments, materials and apparatus.

4. Radiological Physics: the study of physical problems related to the applications of ionizing radiation in clinical medicine.

(b) The Benefits and Risks of Ionizing Radiation

With the increasing complexity of modern living, the medical, social and economic needs of the individual and of his family have become closely related. Hence, when health planning is undertaken, consideration must be given to the results of such planning on the social and economic development of the nation. This is especially true in the radiological sciences. The applications of radiation hold great and substantial benefits to mankind. However, the attendant human exposure which may accompany many of these uses poses a number of health risks. It is therefore clear that health planning in the radiological sciences requires the most careful balancing of benefit against risk if medical, social and economic progress is to take place. Failure to make such plans may lead to economic stagnation in the atomic sciences if

health regulations are too restrictive or too serious dangers to the public health if these regulations are inadequate.

As new developments in the atomic sciences have unfolded, and as the uses of ionizing radiation have become more extensive, the Public Health Service has found it necessary to undertake an increasing number of activities in the radiological sciences. These efforts may be conveniently divided into two interdependent parts:

1. Activities concerned with the control of the *incidental* radiation exposure received by the population from radioactive contamination of the environment and from occupationally related sources; and

2. Activities concerned with the *intentional* application of ionizing radiation in the prevention, diagnosis, treatment and after-care of diseases, injuries and congenital defects.

The responsibilities of the Public Health Service in the field of radiation control were broadly outlined in a report to the Surgeon General by this Committe in 1959[1]. In this report the Committee urged the Service to assume a major role both in the formulation of national policy and the initiation of comprehensive programs in the control of ionizing radiation in the United States. It proposed that the Service take steps leading to its active participation in (1) the formulation of radiation standards; (2) the training of radiological health specialists; and (3) the development of regulatory programs for the protection of the public from all sources of ionizing radiation. There was particular concern for the prevention of undue exposure from radioactive contamination of the environment, from radiation sources used by the health professions and from industrial and other sources contributing to occupational exposure.

In accordance with this report, the Service has established a series of nationwide surveillance networks to monitor environmental contamination. It has supported university programs to train radiological health specialists. It has also undertaken a broad range of activities designed to reduce unnecessary exposure from medical and dental sources of radiation. In the field of occupational exposure, efforts so far have been relatively limited and much more remains to be done.

The place of the Public Health Service in the formulation of radiation standards was clearly defined late in 1959 by the creation, first by Executive Order and then by Public Law 86–373, of the Federal Radiation Council. This agency was given responsibility to advise the President on all matters directly or indirectly affecting health, including guidance to federal agencies on the formulation of radiation standards. The Council includes the heads of six Departments of the United States Government, each having a major interest in the applications and control of ionizing radiation. Through the Department of Health, Education and Welfare, one of the participating agencies, the Public Health Service has made important contributions to the deliberations of the Council.

The FRC has been ably assisted in its work by the National Academy of Sciences to which it turns for guidance in matters pertaining to the biological effects of ionizing radiation. It has also had enormous help from the National Council on Radiation Protection and Measurements. This organization, composed of leading scientists, has for over three decades taken the initiative in setting detailed technical standards designed to protect the individual and the population as a whole from ionizing radiation.

The FRC, with the NAS and NCRP, provides broad supervision of radiation standards in the United States. In general, the FRC has not assumed responsibility for the development of operational standards pertaining to specific radiation problems. The formulation and promulgation of such standards have been left to those federal, state and local agencies which by law are responsible for the registration and licensing of radiation sources. For example, the Atomic Energy Commission has established a system of technical and professional criteria governing the use of reactor-produced radionuclides. Also, an increasing number of states, mainly through their departments of health, have established technical standards for all sources of ionizing radiation. It is noteworthy that although these standards are being formulated in many places, they are remarkably uniform throughout the country because of the guidance provided by the FRC and NCRP.

Although the development of radiation standards in the United States is progressing satisfactorily, this Committee observes a number of gaps which require careful attention in the years immediately ahead. One of these is the absence of standards relating to the qualifications of technical and professional personnel using radiation sources other than those regulated by the Atomic Energy Commission; that is, medical x-ray machines and sources containing radioactive materials that are not reactor by-products. This Committee believes that such standards must be established to assure the public that those who use ionizing radiation are well trained and qualified. It further believes that the Public Health Service, as the principal government agency responsible for the health of the nation, should take the initiative in the formulation of these standards and should seek the coooperation of the health professions in this undertaking.

Another gap is the absence of design standards for radiation sources containing radium and a number of other radionuclides not now regulated by the AEC. Since these sources are frequently the cause of hospital and environmental contamination, the Public Health Service should take early steps to formulate and promulgate appropriate standards for these sources. In assuming this responsibility, the Service should take full advantage of the experience of the AEC, gained in developing similar standards for the sources under its jurisdiction.

A third gap concerns radiation standards for x-ray equipment used in medicine and dentistry. Although basic standards in this field have already been formulated by the NCRP, there is need for a series of standards which may be used as a basis for the premarketing clearance of x-ray equipment. If such standards can be developed in association with a program of premarketing clearance, efforts to reduce unnecessary radiation exposure in the health professions will be materially facilitated.

(c) The Relationship of the Public Health Service to State and Local Health Agencies

The Public Health Service, in developing its role in the radiological sciences, has encouraged state and local health departments to assume major responsibility for the control of ionizing radiation. This is consistent with traditional patterns in public health. Except under special circumstances, the Service has for many years operated within a policy which restricts its own activities in the control of health hazards to those requiring a national effort; e.g., to the development of health standards and to certain laboratory and technical operations which are best performed at the federal level. Regulatory activities, including the licensing of hazardous agents, the inspection of facilities involving health risks and the application of countermeasures to correct health problems, have generally been left to state and local health authorities to administer. The policy is based on the belief that such authorities are usually most familiar with the resources that can be brought to bear on health problems as they arise.

In recent years, the Public Health Service has given moderate amounts of financial support to many state and local health departments for the development of their radiation control programs. Concurrently, many states have adopted laws which give their health departments authority to undertake major responsibility for the control of ionizing radiation. Moreover, recent changes in the Atomic Energy Act[2] have permitted the AEC to begin transferring much of its responsibility for the control of by-product materials to the states.

The assumption of regulatory authority over radiation sources by the states has not been without its problems. Some states after providing their health departments with authority in the field of radiation control have been unable or unwilling to give the funds needed by these departments to perform effectively. Although some states have provided well, adequate resources have not been generally made available to maintain registration and licensing records and to carry out regular systematic inspections. As the use of ionizing radiation in medicine, industry and other walks of life grows, these inadequacies are becoming increasingly serious. Hence, the Public Health Service must remain alert to the dangers inherent in this situation and take appropriate steps to fill the gaps in the nation's program of radiation control whenever necessary.

(d) Radioactive Contamination of the Environment

In 1962, this Committee identified a number of public health problems concerned with radioactive contamination of the environment[3]. It reaffirmed that the Service has major responsibility to maintain appropriate surveillance networks to provide continuing information on levels of environmental contamination affecting the public. It also emphasized the need for the Service to undertake broad research programs to develop countermeasures for the control of environmental contamination. Substantial progress has been made in both of these areas. Although the nuclear weapons test ban appeared to reduce the need for environmental surveillance for a time, current world conditions make a continuing effort in this field essential. Furthermore, as major nuclear facilities for industrial and other peaceful uses become more widespread, the Service's surveillance capability will have increasing value.

In connection with the development of major nuclear facilities in the United States, the Committee notes a continuing problem which might well be alleviated by appropriate action on the part of the Public Health Service. As state and local health departments have assumed an increasing role in the control of ionizing radiation, the Atomic Energy Commission has quite properly retained responsibility for the licensing of major nuclear facilities. Such facilities involve potentials for contamination which are interstate in extent and hence require a central regulatory authority.

Notwithstanding the basic wisdom of this policy, this Committee observes a continuing apprehension on the part of the public when new nuclear facilities are contemplated. It believes that this is unfortunate for it not only postpones the day when the public is able to share in the many benefits provided by the nuclear sciences but it also engenders fears which are costly in terms of public health. To help solve this problem, competent health authorities should play a more prominent role in the consideration of public health factors affecting the construction and operation of major nuclear facilities. Not only is the advice of such authorities essential from the standpoint of the health risks of people working and residing in the vicinity of the facility, it is important that authorities having no official responsibility for the promotion of a nuclear facility play a substantial part in the judgments that must be made when the facility is proposed.

This problem is likely to become increasingly serious in the years ahead. At present, only a small fraction of the nation's electrical power is produced by nuclear facilities. However, in the next few decades, demands for electrical power from nuclear sources are likely to increase as the relative amounts of fossil fuels decrease. It therefore appears imperative that public health authorities henceforth play an important role in matters pertaining to the construction and operation of major nuclear facilities. The health risks involved in any proposed major nuclear facility require the independent appraisal by official health agencies.

(e) Medical Applications of Ionizing Radiation

In foregoing discussions, attention has been directed to certain gaps in programs to protect the public against undue radiation exposure. A number of problems have been identified and solutions for them proposed. These problems have not been discussed in depth because the Committee wishes to direct its major attention in this Report to a series of problems concerned with the uses of ionizing radiation in the health professions. These problems relate to weaknesses in the teaching of the clinical application of ionizing radiation, including radiation protection, which have resulted from manpower shortages.

It is appropriate that these matters receive intensive review at this time. New health programs (Titles 18 and 19[4] and the program for cancer, heart disease and stroke) proposed by the President and approved by Congress are likely to place increasing strain on the radiological manpower and teaching resources of this nation in the years ahead. Concern for these problems has recently been voiced in a report by the Committee on Appropriations of the United States Senate under the chairmanship of Senator Pastore[5].

IV. Manpower Shortages and Related Academic Problems in the Radiological Sciences

Although the radiological sciences had their origin only a little over a half century ago, their importance to medicine and dentistry has grown with unusual rapidity. A recent study by the Public Health Service[6] has shown that in 1960-61 over 89 million medical and 48 million dental x-ray examinations were carried out annually in the United States. This represents on average the performance of one medical examination for every two individuals in the population each year and one dental examination for every four. Such a demand for clinical service clearly indicates that the radiological sciences in the short space of seventy years have become one of the major disciplines of American medicine, exerting a substantial and continuing influence on the care of every man, woman and child.

The spectacular growth of the radiological sciences in the health professions has not been without its problems. Indeed, such growth is responsible for the recent development of a serious shortage of professional and technical personnel which threatens the quality of medical care as well as the success of many of the government's health programs. These shortages are particularly evident in academic departments of radiology where they have restricted efforts to provide adequate instruction of medical and post doctoral students in the clinical applications of ionizing radiation including radiation protection. The magnitude of this problem may perhaps be best illustrated by a comparison of growth patterns in demand for radiological service which have developed in recent years with corresponding growth patterns in radiological manpower.

(a) Growth in clinical demand for radiological service

In the diagnostic roentgenology, the discipline concerned with the use of x-rays in the diagnosis of disease, the demand for clinical service is reflected in part by the annual consumption of medical x-ray film. This is because such film plays a basic role in the performance of almost every x-ray examination. Annual consumption data for medical x-ray film in the United States from 1947 to 1963 are shown in figure 1. During this time, film consumption increased at an average annual compounded rate of almost 5.4 percent.

While these are impressive data, denoting a doubling of consumption every thirteen years, they do not indicate the total growth that has taken place in the demand for diagnostic x-ray service. Since World War II, advances in medical research have caused the emergence of important new roentgenological methods which have added clinical demands largely unreflected by film consumption data. These methods are the outgrowth of two technological innovations occurring in the early 1950's; the first was the development of instrumentation by which fluoroscopic images can be amplified in brightness many thousands of times. Prior to this, physicians working in the field of diagnostic roentgenology were restricted in their use of x-rays to relatively simple examinations. More complicated procedures requiring prolonged fluoroscopy and the recording of radiological data on motion picture film were quite impracticable because excessive amounts of radiation were needed with techniques then available. The development of fluoroscopic amplification changed all this and and a new era of diagnostic roentgenology began. The second technological innovation was the development of the rapid film-changer, a device with which large numbers of radiographic exposures can be made in quick succession to provide a detailed record of rapidly occurring events.

Together, the fluoroscopic amplifier and the rapid film-changer have made possible the development of an increasing number of complex radiological procedures of fundamental importance in the diagnosis of many diseases. Some of the more noteworthy of these include angiocardiography, a procedure which permits the physician to study in detail the structure and physiology of the heart and its great vessels; cerebral arteriography, a method devised for the intensive investigation of the circulation of the central nervous system; and cinefluorography, a procedure using x-ray motion picture techniques to evaluate abnormal anatomical and physiological states in a broad range of body systems.

FIGURE 1—Index of medical x-ray film consumption. This index has been calculated from data on the gross square footage of x-ray film produced annually in the United States, less film diverted for industrial and dental uses and adjusted for film exported and imported.

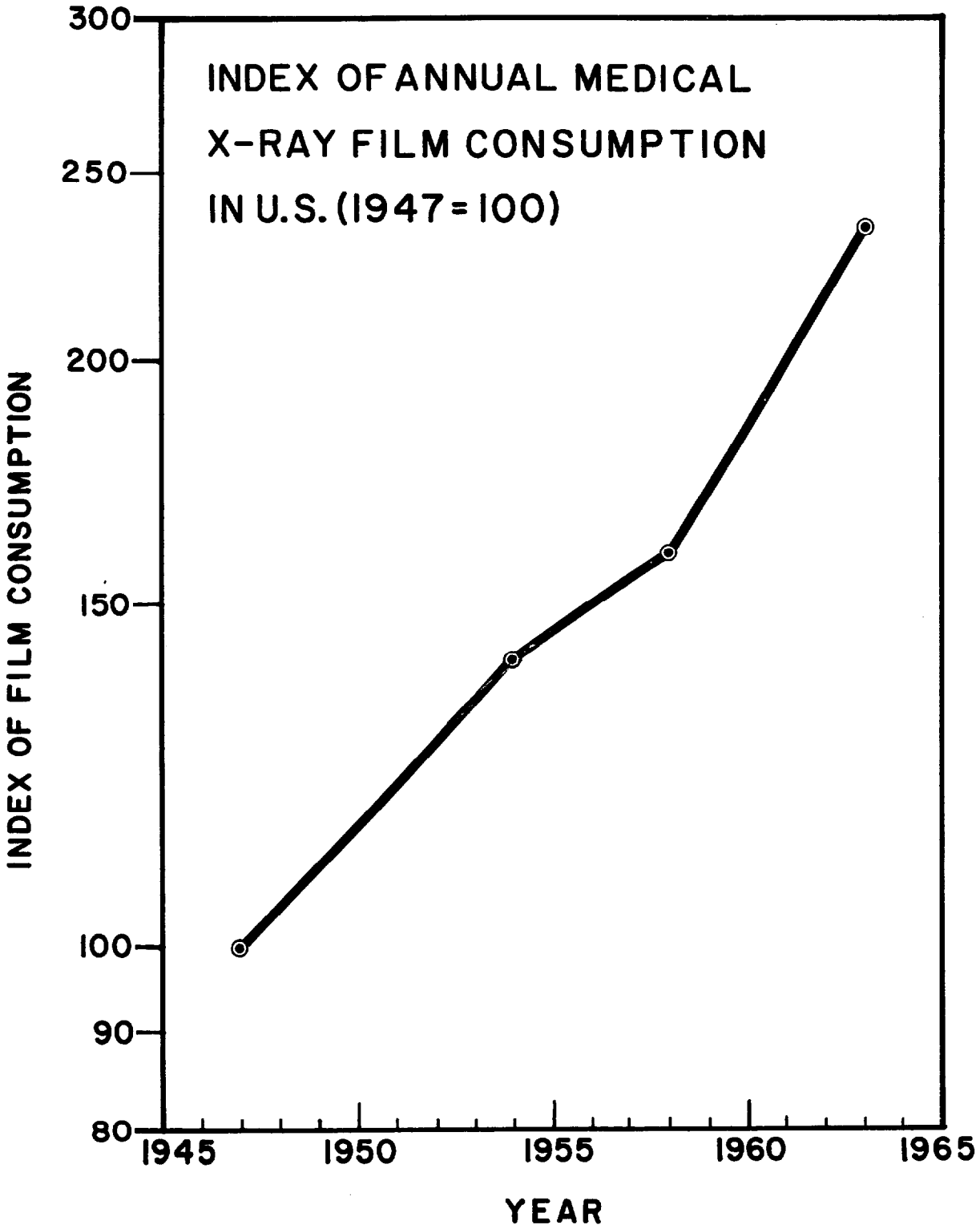

FIGURE 1.

One of the most important characteristics of these new methods is that they need much more time and effort for their performance than do older, more conventional techniques. Indeed, they have a great deal in common with major surgical procedures, requiring for each examination considerable numbers of highly trained professional and technical personnel and large outlays of special roentgenological and physiological equipment. In most instances, only two or three of these special examinations may be completed in one day by one team of workers.

The benefits of these new methods are substantial, particularly to those patients with cardiovascular and neurological diseases. However, it must be recognized that they place an unusually heavy burden on radiological manpower.

Data which give a measure of this burden have been unavailable heretofore. Hence, the Committee undertook a study based on the records of a random sample of 17 large, university hospitals*, widely distributed throughout the United States, to obtain this information. Six of the hospitals were in the eastern part of the country, six in the midwest, three on the west coast and two in the south. In this group of institutions, over 1.31 million diagnostic x-ray examinations, including 37.2 thousand special roentgenological procedures, were performed by an aggregate professional staff of 177 radiologists during the year 1964. The equivalent of 44 radiologists was needed for the special examinations. Although the institutions included in this study are not entirely representative of all hospitals in the United States, they are perhaps sufficiently so that the following conclusions may be drawn: 1. The number of special examinations currently performed is relatively small, amounting to less than 3% of all examinations undertaken, and has little influence on film consumption statistics. 2. These examinations, on the other hand, are sufficiently complicated and time-consuming that their performance absorbs about 25% of the professional manpower in diagnostic roentgenology. This suggests that film consumption at most reflects only three-quarters of the total demand for diagnostic x-ray service. Furthermore, because the growth in special examinations has taken place largely in the past fifteen years, it suggests that the demand for roentgenological services currently is growing at a rate at least one-third greater than the 5.4% annual rate indicated by film statistics alone; that is, total demand is increasing at a rate in excess of 7.2%.

In *radiation therapy*, clinical demand is related to the frequency of occurrence of cancer because this method of treatment has been reserved more and more for patients with malignant neoplasms. For several decades, the number of persons having cancer has increased as the population has become larger and as more individuals have lived to advanced age when cancer is more common. Recently, cancer deaths have been rising at an annual rate of about 2%, as shown in figure 2[7], where data on the number of deaths per year from cancer of all sites in ten states and the District of Columbia are given for the period from 1935 to 1960. It seems likely that the increase in clinical demand for radiation therapy has at least equaled this rise.

In *nuclear medicine*, the branch of the radiological sciences which pertains to the application of radioactive materials to the diagnosis of disease and to the study of physiological processes in man, the demand for clinical service is difficult to evaluate. Such demand is not reliably reflected by amounts of radioactive materials produced for medical use because diagnostic applications of nuclear medicine, requiring relatively small individual quantities of these materials, are growing at a much faster rate than therapeutic procedures, for which large quantities are needed[8]. The number of persons licensed to use radioactive materials for medical purposes also is not a reliable index of the demand for clinical service because the number of examinations performed each year is increasing much more rapidly than the number of licensees. In the 17-hospital study car-

* Massachusetts General Hospital, Boston; New York Hospital, New York; Presbyterian Hospital, New York; University of Pennsylvania Hospital, Philadelphia; Johns Hopkins Hospital, Baltimore; Strong Memorial Hospital, Rochester, New York; University Hospitals of Cleveland; Ohio State University Hospital, Columbus; Cincinnati General Hospital, Cincinnati; Billings Hospital, Chicago; Indiana University Medical Center, Indianapolis; University of Minnesota Hospital, Minneapolis; Emory University Hospital, Atlanta; John Sealy Hospital, Galveston; University of California Hospital, Los Angeles; University of California Hospital, San Francisco; and the Affiliated University Hospitals, Seattle.

FIGURE 2—Numbers of deaths per year from cancer of all sites in ten states and the District of Columbia [7].

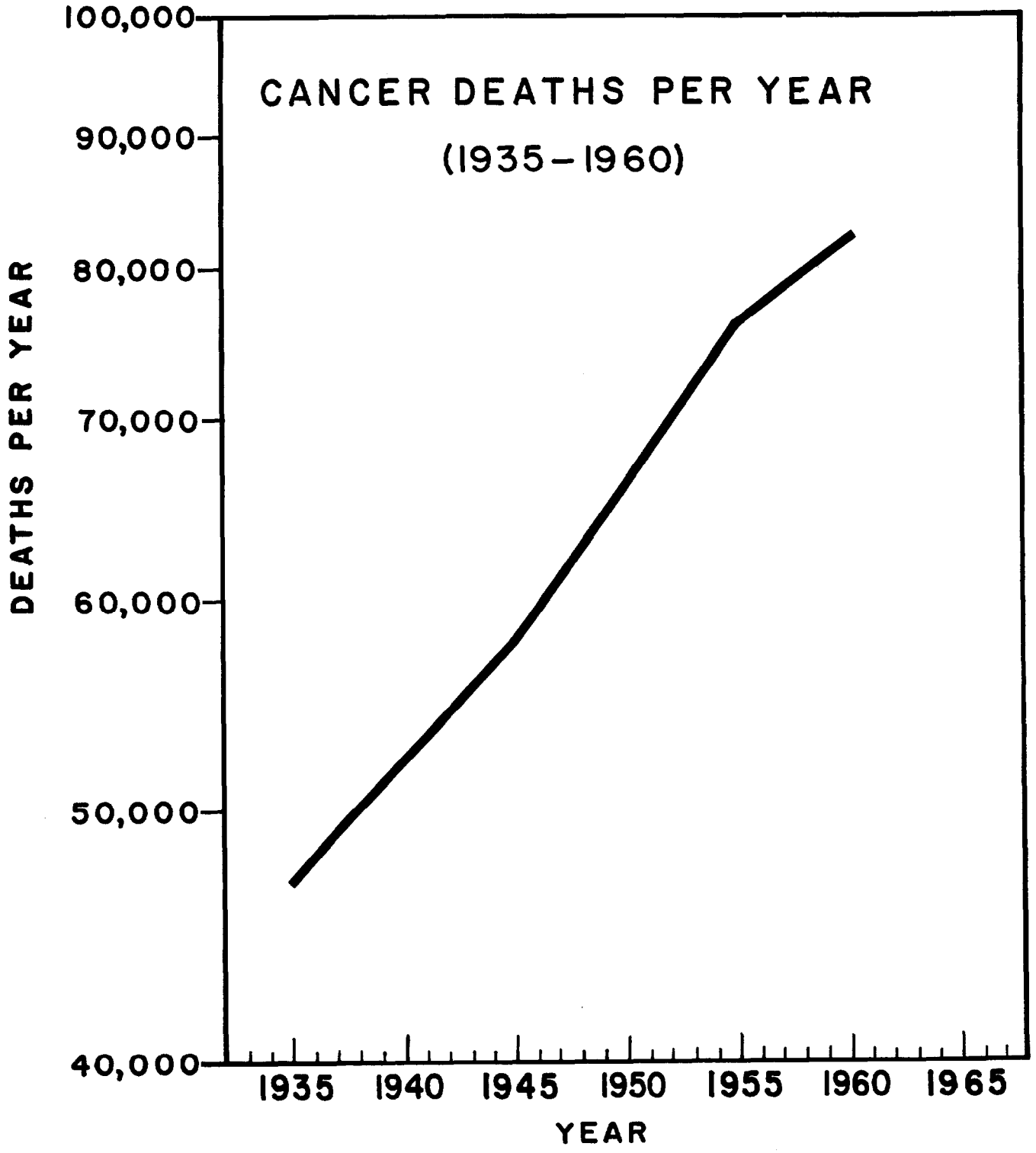

FIGURE 2.

ried out by this Committee, data were collected which indicate that demand for clinical service has risen in the brief span of a few years to a level requiring more than one-tenth of the professional manpower devoted to clinical radiology (see table I). From a perusal of hospital records in a few institutions where patient statistics in nuclear medicine have been maintained for an adequate period of time, it is estimated that this discipline's clinical demand currently is growing at a rate of at least 15% per year.

TABLE I—Distribution of Professional Staff, Arranged According to Radiological Discipline, in 17 University Hospitals.

Radiological Discipline	Number of Individuals	Per Cent of Total Staff
Diagnostic Roentgenology	155	72.1
Radiation Therapy	35	16.3
Nuclear Medicine	25	11.6
TOTAL	215	100

(b) Growth in physician manpower in the radiological sciences

The growth in professional manpower available in the clinical divisions of the radiological sciences is illustrated graphically in figure 3. These data, from statistics collected by the American Medical Association[9], give the number of radiologists in practice in the United States for the period of 1949 to 1964. It will be observed that the number of these specialists grew from about 2,900 at the beginning of the period to more than 6,900 at the end, a compounded annual growth rate of 5.9%. At first glance, this growth seems remarkably good, substantially exceeding that of physicians in general. However, it falls considerably short of the growth needed to meet demands for clinical service as the following makes clear.

Previous discussion has shown that the demand for diagnostic x-ray service for the last 15 years has grown at an annual compounded rate of 7.2% or more. In radiation therapy the increase has been at least 2% per year and in nuclear medicine, 15% per year. Taken together, after suitable weighting for the relative manpower requirements of each of the three clinical divisions of the radiological sciences, these data indicate a composite compounded annual growth rate of 7.1%.*

The foregoing data clearly indicate that in the years following World War II, growth in the clinical demand for radiological service has substantially exceeded the growth of physician manpower to meet this demand. An increasing manpower deficit of this sort must always be cause for concern. However, it is particularly disturbing in this instance because, for many years preceding the war, the training of medical specialists was sharply restricted due to the depression and thus even the number available at war's end was inadequate. There can be little doubt then that there has developed in the radiological sciences a shortage of physician manpower of serious proportions.

This situation has been further aggravated by a recent change in attitude adopted by the medical profession toward the use of radiological methods in the practice of medicine. In the past, many physicians have employed x-ray machines in diagnosis and treatment even though their training in the use of these devices has often been limited. However, in the late 1950's, the profession became increasingly aware of the dangers of a physician's using ionizing radiation without his having had special training. The American Academy of Pediatrics[10], for example, advised all pediatricians to discontinue fluoroscopy of their patients whenever possible and to have their diagnostic x-ray studies performed by radiography, where the radiation exposure is generally less. Because of this and similar recommendations from other groups, a substantial number of physicians not trained in the radiological sciences, but who have previously employed radiological methods in their practices, are discontinuing their use.

There can be little question that this action is desirable. However, its effects are to impose additional burdens on radiologists and to aggravate the shortage of trained manpower beyond that indicated by the foregoing discussion.

* This growth rate was calculated from the formula,

$$G = g_d p_d + g_t p_t + g_n p_n$$

where g_d, g_t and g_n are the annual growth rates in demand for clinical service in diagnostic roentgenology, radiation therapy and nuclear medicine respectively and p_d, p_t and p_n are the percentages of the total professional manpower presently engaged in the clinical radiological sciences which apply to the respective three divisions. In this calculation, data for p_d, p_t and p_n were taken from table I.

FIGURE 3—Number of clinical radiologists (less radiologists in training) practicing in the United States.

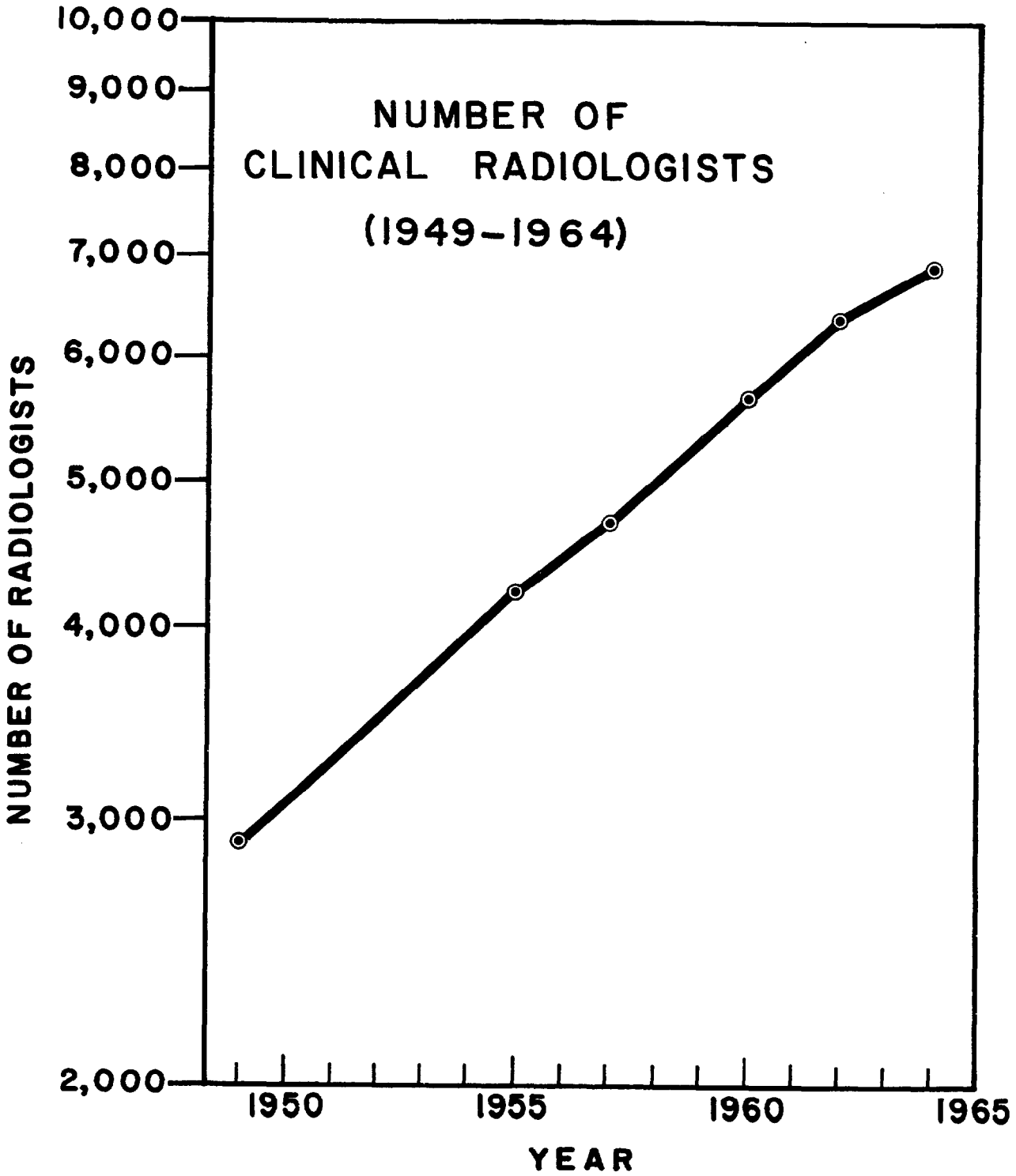

FIGURE 3.

It is difficult to estimate precisely the magnitude of the physician shortage currently prevailing in the radiological sciences. However, the combined effect of all of the factors which have contributed to this shortage must be substantial. Certainly, the deficit in manpower requirements amounts to many thousands of physicians. *Indeed, it appears that the number of radiologists needed in the United States is almost twice as great as the number actually available.*

(c) Future needs in physician manpower in the radiological sciences

In a field where the growth has been so inexorable as in the radiological sciences, manpower shortages are likely to become worse with the passage of time. It is therefore important in health planning to examine future needs as well as to evaluate current problems. It is reasonable to assume that the growth patterns prevailing in the demand for radiological service over the past fifteen years will continue in the years ahead. Advances continue at a rapid pace in medical research. Large new programs of health care are in the process of development, and the public is demonstrating an increasing insistence on comprehensive medical care of high quality.

If present growth rates in clinical demand continue, the need for physician manpower in the radiological sciences seems likely to rise to a level of three or more times current supply by 1975, i.e., to a level of from 20,000 to 25,000 radiologists in ten years. Such a need presents a disturbing picture to those responsible for the nation's health. It is clear that major attention must be given to the problems of radiological manpower as quickly as possible.

The correction of manpower shortages depends in part upon the availability of potential resources. These resources include training facilities, the supply of instructional personnel and supporting funds. Data on training positions in the clinical radiological sciences in the United States are shown in figure 4[11]. These depict the total number of hospital residency positions, both available and filled, for training radiologists from 1954 to 1963. It will be observed that the number of positions rose only slightly during this period from about 1,650 in the beginning to just over 1,950 at the end. Also, 24% of the positions remained unfilled on the average during this interval. In recent years, about 1,500 positions have been filled, including those occupied by foreign trainees. Because the length of residency training in radiology is normally three years, the number of individuals completing their training each year is currently about 500. Death and retirement reduce this number to a net increase in radiological manpower of about 300 per year.

If the present shortage of professional manpower in the radiological sciences is to be alleviated, almost 1,500 physicians must enter radiological training each year over the next decade; that is, the current number who begin training must be increased threefold. Also, the number of training positions must be more than doubled to a level in excess of 4,500.

It will be apparent to even the most optimistic that these goals are not likely to be attained. They require that over 20% of the medical students graduating each year enter radiological training. If this were to happen, it would almost certainly create serious dislocations in other branches of medicine. Therefore, to meet the increasing demands for radiological service, the nation must settle for more modest increases in the number of trainees and seek ways in which the available manpower in radiology may be used more effectively. Every modern educational, administrative and technological means must be investigated to improve the efficiency with which radiological service is provided. Funds to support this type of radiological research must be given high priority.

(d) Causes of physician manpower shortages in the radiological sciences

Even partial correction of physician manpower shortages in the radiological sciences will be difficult. A full understanding of the causes of these shortages is necessary if successful methods to meet the problem are to be devised.

One of the principal causes of difficulty, the unusual increase in demand for radiological services during the past several decades, has

FIGURE 4—Residency training positions for radiologists in the United States.

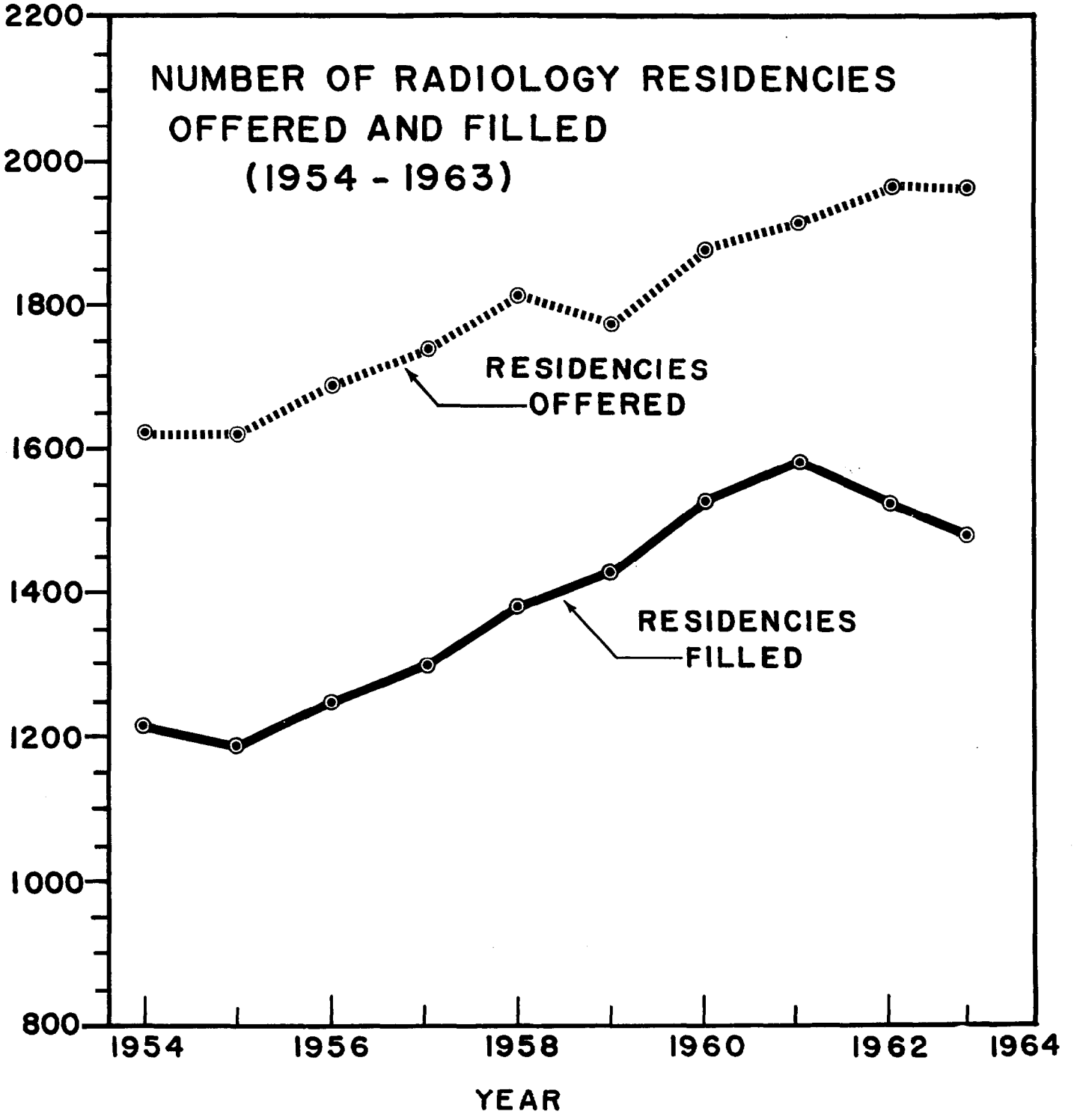

FIGURE 4.

been discussed. Another problem is the general shortage of physician manpower, which has affected all health professions in recent years. The number of graduates of medical schools in the United States has increased very slowly during the postwar period, from about 6,000 per year immediately following World War II to just over 7,300 in 1964[12]. This is barely equal to the growth rate of the nation's population during the same period and, in recent years, has been less (see figure 5). Such a rate is clearly insufficient to meet the increasing demands for medical service created by advances in medical research and by the expansion of services to lower income groups through various forms of insurance. To obtain more radiological trainees, therefore, it will be necessary, among other things, to take steps which will assure the graduation of more physicians each year from this country's medical schools.

Although general manpower shortages in medicine are aggravating the personnel problems of the radiological sciences, they by no means constitute the only or principal cause of difficulty. The percentage of unfilled residency training positions in radiology is among the highest of the major clinical specialties[11]. Of perhaps greater significance, the 17-hospital study undertaken by this Committee found that, of those who enter the clinical radiological sciences, only one quarter decide to do so when they are in medical school; of the remainder, half make their decision during internship and half after they have entered residency in some other medical specialty, private practice, or the military services (see table II). This is in sharp contrast to the experience of those entering such specialties as medicine, surgery and pediatrics, where prevailing practices of selection make it almost imperative for a prospective trainee to make his decision before graduation from medical school. The disproportionately large number of unfilled residency training positions in radiology and the large number of trainees who decide to enter the specialty rather late in their careers, frequently as a second choice, indicate clearly that there are deep-seated troubles within the clinical branches of the radiological sciences themselves.

TABLE II—Time at Which Physicians Decide to Make Radiology a Career.

Data are from Study of Resident Staffs of 17 University Hospitals in the United States during the year 1965.

Time of Decision	No. of Resident Radiologists Making Decision	Per Cent
Before or During Medical School	73	26
During Internship	103	37
After Internship	104	37
TOTAL	280	100

These troubles are not difficult to find. One has only to examine the departments of radiology of American medical schools to discover that few are likely to attract many students to careers in the radiological sciences. Faculty time is largely devoted to the provision of radiological service to patients and to associated administrative functions. Little time is set aside for teaching, particularly at the predoctoral level, and much less for research.

Under these circumstances, it is not surprising that the medical student, before graduation, frequently finds little to interest him in radiology. To him, the clinical radiologist is a man whose time is wholly taken with routine clinical service, often given under conditions where doctor-patient relationships are rather distant, and hence, disappointing. Also, in his contact with the radiological faculty, in contrast to his experience in other clinical disciplines, the student sees little evidence of exciting research. Indeed, in many academic departments little or no research of consequence can be found at all. The student is aware of the radiologist's participation in the many conferences and seminars he must attend; but even here, it seems that the radiologist's role is quite subordinate, even though the information he provides is often decisive. In short, the radiological sciences do not present an inviting picture to most medical students.

The paucity of experimental research in academic departments of radiology may come as a surprise to many because the major advances which have taken place in this field could not have been achieved without substantial amounts of research by someone. An investigation, however, shows that much of this research has been

FIGURE 5—Number of physicians graduated from American medical schools each year per 100,000 population.

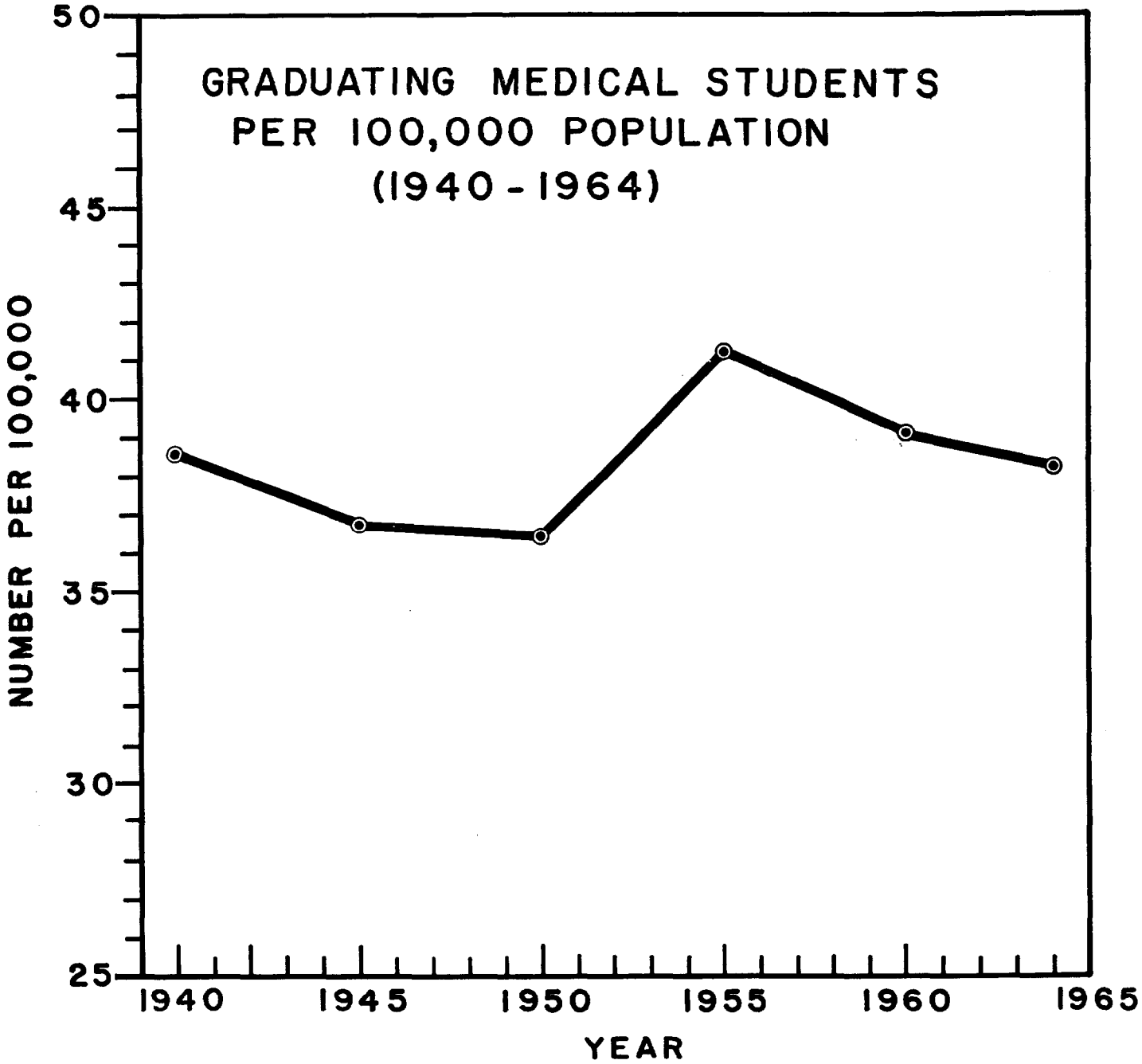

FIGURE 5.

done by workers in other clinical disciplines. The reasons for this are perhaps twofold. First, the clinical service burden imposed upon the academic radiologist allows him little time for research. Second, and perhaps as important, the clinical radiologist, as American medicine is practiced today, does not have at his immediate command one of the basic ingredients of clinical research, namely, patient material. If such a physician wishes to embark on a program of clinical investigation, it is usually necessary that he first stimulate the interest of a colleague in one of those clinical disciplines that have access to patients. If such interest can be aroused and if there are available facilities in which the work can be undertaken, only then can the research move forward. In most cases, facilities for radiological research are not available. In the great majority of the departments of radiology of American medical schools studied by this Committee, there is neither space nor equipment assigned for clinical investigation. Where research is being done, hospital x-ray facilities are used at odd moments when they are not employed for service functions, a situation which is often detrimental to patient care as well as to research.

The meagerness of the research effort, characteristic of academic departments of radiology in the United States, is well demonstrated by statistics pertaining to funds distributed by the Public Health Service, including the National Institutes of Health, for the training of research personnel.[13] During the fiscal year 1964, just under $170 million were allotted to medical schools and other research institutions for pre- and postdoctoral training grants and traineeships. Of this, only 1% went to academic departments of radiology. There can be little question that this represents an undesirably low level of support for a discipline which, as will be pointed out later, needs to attract close to one-tenth of the graduates of American medical schools.

The distribution of this support among the three clinical divisions of the radiological sciences is shown in table III. It is noteworthy that the funds made available to diagnostic roentgenology, the largest of the radiological divisions, amounted only to a little more than a half million dollars, or 0.33% of all PHS training funds. In nuclear medicine, funds for research training are also inadequate, amounting to approximately $200 thousand or a little more than 0.1% of all monies available. Even in radiation therapy, with support approaching $1 million, funds fell short of need.

Data on the distribution of PHS funds for research indicate that the amount of support allotted to academic departments of radiology is also small.[14] This is particularly so in diagnostic roentgenology and nuclear medicine. This is not to say that radiological research is poorly supported by government. As previously indicated, substantial amounts of money have been made available for such research in departments other than radiology. However, funds going to radiology departments are sharply limited.

In discussing the shortcomings of academic radiology, the Committee has emphasized deficiencies in research because of the importance that research has assumed in American medical education during the past decade or two. Coggeshall,[12] in a recent report to the Association of American Medical Colleges, points out that medical education has been going through a transition in which the emphasis has been transferred from the accumulation of facts, largely by memory, to a better understanding of the mechanisms involved in the development of normal tissues and their disease states. The research method has played an important role in this. Until now, experience in research in predoctoral years has been regarded as necessary only for those who intended to pursue scientific or academic careers. However, such experience is now considered essential to the education of the general practitioner and specialist as well. Consequently, ample opportunity for student participation in research must be made an integral part of predoctoral medical education. Teaching and research have become complementary components of the educational process. Together with clinical experience, instruction and research comprise the essential ingredients of modern education in the health sciences.

It is therefore clear that academic departments of radiology cannot perform their educational function unless strong efforts are directed

TABLE III—Funds made available for research training by the Public Health Service, including the National Institutes of Health, during the fiscal year 1964 [13].

Discipline	Predoctoral Training Grants	Postdoctoral Training Grants	Traineeships	Total
Diagnostic Roentgenology	$25,000	$315,739	$220,000	$562,739
Radiation Therapy	—	857,485	129,500	986,985
Nuclear Medicine	—	195,145	—	195,145
Totals	$25,000	$1,368,369	$351,500	$1,744,869
All Disciplines	$14,806,500	$151,101,372	$3,929,383	$169,837,255

toward the improvement of their research capability.

In addition to the difficulties just cited, there is yet another problem which has reduced the number of teachers in radiology and hence has made the recruitment of physicians for the radiological sciences more troublesome. This problem comprises a complex series of economic relationships which together form a repeating chain of difficulties, each of which causes or exaggerates the next. The broadening demand for clinical service and the increasing shortage of trained physicians have combined to create economic forces which have placed sharp upward pressure on the professional fees of practicing radiologists. Because the financial status of the academic radiologist must be tied more or less closely to that of his academic colleagues in other clinical disciplines, a serious economic gap has developed between the incomes of academic and practicing radiologists which is diverting many a prospective academic radiologist to private practice. This problem is not likely to be resolved until manpower shortages are alleviated.

(e) Current trends in academic radiology

Although the picture of academic radiology in the United States is distressing, a few medical schools have recently made substantial progress in strengthening their departments of radiology. With the assistance of funds provided by the government and other sources, faculties have been increased and research facilities constructed. Although a great deal still needs to be done, it is clear that with intensive effort, supported with adequate funds, academic standards in radiology can be raised to levels consistent with the best of other medical school disciplines.

As plans are made to improve the depth and quality of academic radiology, it must be constantly borne in mind that medicine has undergone enormous changes in the United States since the end of World War II. As the diagnosis and treatment of disease have become more complex, trends toward specialization have intensified. The radiological sciences have shared in this specialization. Increasing numbers of radiologists have found it necessary to restrict their work to such fields as cardiology, neurology or pediatrics. The need for further specialization has arisen largely from the development of new and complicated roentgenological procedures which require extended periods of training and a penetrating knowledge of the subject material.

It has previously been pointed out that many of the radiological advances that have taken place in recent years have been developed by clinical investigators in disciplines outside of radiology. To some, this has seemed unfortunate. However, it has provided a superb opportunity to infuse academic radiology with much-needed strength. Internists, pediatricians, and others whose research has taken them into radiological territory can do much to revitalize the specialty. To be completely effective, of course, these physicians must be accepted as full members of the radiological faculty. If such physicians are wisely assimilated, they will be of great assistance in transforming academic radiology into an attractive and stimulating discipline, well balanced in teaching, research and clinical service to patients.

The field of radiology in general and academic radiology in particular could also be markedly benefited if increasing numbers of radiologists were to play a larger role in the research, teaching and service functions of other medical disciplines, thus developing a counterpart to the trend just cited. An effective research program in the radiological sciences requires a thorough understanding of the needs of the clinician. Such understanding in many cases can only be attained by day-to-day association with investigators in other clinical disciplines, on the wards and in the experimental laboratories.

In a field such as radiology, whose activities embrace almost every clinical discipline, it perhaps may seem unnecessary to speak of the need for strong interdisciplinary ties. However, as academic radiology has found itself more and more restricted to the provision of clinical service to patients, it has become increasingly isolated. In the years ahead, it is incumbent upon every faculty member in the field to break through the barriers of isolation and to strengthen his associations with other clinical disciplines. To do otherwise will lengthen the time before academic radiology assumes its proper role in the health sciences.

(f) Other manpower needs in the radiological sciences

Although shortages in physician manpower are of great concern, they are not the only gaps in personnel prevailing in the radiological sciences. Similar gaps exist in: (1) non-physician professional manpower, including radiological engineers, radiochemists, radiological physicists, radiobiologists, and radiological health specialists; (2) technical personnel, including clinical x-ray and nuclear laboratory technologists; and (3) other supporting personnel, including nurses and administrative staff.

Radiological Engineers: Engineering has played a prominent part in the development of all of the radiological sciences. However, its importance is only now becoming fully recognized. The role of the radiological engineer is twofold: (1) to develop the broad range of radiological instruments, materials and apparatus needed by the health professions and (2) to supervise the technological operations of departments of radiology. The instrumentation needed by the radiological sciences has become so complex that highly skilled engineering talent is necessary not only for its design but also for its application in clinical practice. Hence, there has arisen a need for the radiological engineer to assume a direct clinical role in close association with the radiologist.

Training programs needed for the development of radiological engineers currently do not exist. Hence, such programs should be initiated without delay. They must be highly specialized, providing not only experience in the physical sciences but in several of the biomedical disciplines as well. The trainee must acquire competence in such diverse fields as electronics, optics, information theory, mechanical engineering, computer technology and electricity and magnetism; he must also take substantial amounts of work in such subjects as human anatomy and physiology. This background is essential if he is to design effectively the advanced instrumentation needed by the radiologist or if he is to achieve his greatest usefulness as a technological advisor to the clinical personnel with whom he is associated.

The recent emergence of radiological engineering as an important scientific discipline has created a demand for radiological engineers that is difficult to fill. This manpower gap requires early correction if American medicine is to maintain a leading position in the radiological sciences. Hence, training programs for such engineers should be undertaken promptly.

Radiochemists: Radiochemistry had its origin in the 1930's. In the biomedical field, it grew out of the need for synthetic processes in which radioactive materials are incorporated into complex organic molecules for use either as radiopharmaceuticals or as components of biochemical systems in fundamental research. In the rapid advances which have taken place in nuclear medicine in recent years, the radiochemist has played an important and perhaps even a dominant role. Indeed, progress in nuclear medicine is highly dependent upon the ability of the radiochemist to provide a continuing series of useful radiopharmaceuticals.

As with the radiological engineer, the training requirements of the radiochemist are stringent. Basic experience must be provided in the

disciplines of inorganic, organic and physical chemistry. Additionally, intensive training must be provided in biochemistry, pharmacology and in the sophisticated techniques of complex organic synthesis.

Because of the rapid growth of nuclear medicine and of the applications of labelled compounds in biological research, radiochemists are in short supply. Hence, in the opinion of those in the field, it is urgent that training programs to develop these specialists be undertaken as soon as possible. The speed with which the products of atomic research can be translated into medical benefits for the public is largely dependent upon the availability of such personnel. The growth of nuclear medicine therefore will be sharply curtailed unless the supply of radiochemists is substantially increased.

Other Non-Physician Specialists: In radiobiology and radiological physics (including health physics and nuclear engineering), the Atomic Energy Commission recognized several years ago the need for additional personnel in these fields and established a series of training programs to meet this demand. Also, the Division of Radiological Health, Public Health Service, took steps to provide the manpower required to maintain safe operating practices in the radiological sciences when it instituted in 1960 a program of training grants for radiological health specialists. These programs have been increasingly effective in supplying needed scientific personnel. Their success clearly indicates that serious effort should now be made to provide support for the training of all scientists needed in the radiological sciences.

Technical Manpower: In the field of technological manpower, serious difficulties currently prevail in the provision of adequate numbers of clinical x-ray and nuclear laboratory technologists in the United States. Recently, at the President's White House Conference on Health, it was pointed out that members of the paramedical disciplines, including technologists, have been underpaid for many years. Consequently, the field of technology has been relatively unattractive to graduating high school students who are seeking vocational opportunities. This is particularly true in the case of male students, even though many such students have much to offer the radiological sciences because of their inherent aptitudes. Furthermore, the long-term employment stability of such individuals is highly desirable. The foregoing is not to say that the opportunities for female technologists in the radiological sciences are limited. On the contrary, they are unusually bright. However, experience has shown that the majority of female technologists pursue their careers for only three to four years before leaving it for marriage.

The fields of x-ray and nuclear technology are sufficiently stringent in their training requirements that two years or more of training beyond the high school diploma are necessary for an individual to become a competent technologist. Such an educational background justifies a wage scale which is competitive with other vocations having similar standards. It is to be hoped that, in the years ahead, the lot of the chronically underpaid technologist may be improved. Without this change, it will become increasingly difficult to increase the effectiveness with which radiological services are delivered to the public. The establishment of minimum legal standards of education, training and experience for such technologists appears to be necessary to bring this about.

Because technological manpower is so important to all of the radiological sciences, the Committee believes that the Division of Radiological Health, Public Health Service, should undertake as soon as possible a broad study of the technological manpower requirements of the United States to determine the magnitude of current shortages and to recommend ways and means by which these shortages may be corrected. In making this study, the Service should seek the cooperation of all professional and technological groups having an interest in this subject. Among these may be included the American College of Radiology, the American Society of Radiologic Technologists, the Health Physics Society and the Radiation Research Society.

(g) The correction of manpower shortages in the radiological sciences

From the foregoing discussions, it is apparent that the correction of manpower shortages in the clinical divisions of the radiological sciences

is clearly linked to the strengthening of academic departments of radiology in American medical schools. Radiological faculties must be strengthened and funds for research facilities must be made available as the development of academic radiology broadens and matures. Funds must also be made available for the training of additional radiologists, medical students, non-physician professional personnel and technologists.

This Committee envisions the need for a broad series of training and research programs in the radiological sciences. These programs are required to upgrade the quality of the radiological services which have become such a critical part of medical and dental care and to improve radiation protection practices in the health professions. In the field of training, these programs may be divided into three principal categories: (1) a series of programs to strengthen radiological instruction of medical students and to increase the number of academic and practicing radiologists; (2) a series of programs to increase the number of radiological engineers, radiological physicists, radiobiologists, radiochemists and radiological health specialists; and (3) a series of programs to provide quality training to increasing numbers of technologists (See table IV).

TABLE IV—Training Programs Required in the Radiological Sciences

I. Professional—(Physicians)
- Predoctoral Training—Institutional support
- Postdoctoral Training—Institutional and individual traineeship support
  - (i) clinical radiologists
  - (ii) academic radiologists

II. Professional—(Non-Physicians)
- Undergraduate Training—Institutional support
- Graduate Training—Institution and individual traineeship support
  - (i) radiological engineers
  - (ii) radiochemists
  - (iii) radiological physicists
  - (iv) radiobiologists
  - (v) radiological health specialists

III. Technological
- Undergraduate Training
  - (i) x-ray technologists
  - (ii) radiation therapy technologists
  - (iii) nuclear medicine technologists

Physician Training:

As in most clinical disciplines, the types of training programs needed for physicians are dependent upon the academic level for which they are intended.

At the predoctoral level, funds are needed to strengthen the faculties of academic departments of radiology. By this, the radiological background of all physicians can be improved and more students attracted to careers in radiology. Major effort must be made to communicate to the student the exciting professional opportunities available to him in a radiological career.

At the postdoctoral level, two types of programs are required: one to train substantial numbers of men who may be expected to enter the practice of radiology and one to train men who may be expected to follow academic careers.

Practicing Radiologists: In the past, the Public Health Service has provided only limited funds for the training of clinicians. However, a few years ago such support was introduced in the field of psychiatry and mental disease. At the time, this discipline was suffering many of the problems currently facing the radiological sciences. Physician manpower was grossly inadequate to meet the public's demand for psychiatric service. Psychologists, social workers and many other supporting personnel were in short supply. It was necessary to undertake bold new programs to meet the challenge which these problems presented. After long and careful thought, a residency training program for practitioners in psychiatry was undertaken. Its success is now well known. Not only have increased numbers of physicians been attracted to the specialty but their caliber has improved substantially as well.

The success of this program suggests that it might well be adapted to increase the number of residents entering the field of radiology. Indeed, the Committee believes its initiation to be of the greatest urgency.

In the early phases of the residency training program in psychiatry, funds were distributed mainly to educational institutions to strengthen teaching faculties and to provide such equip-

ment, supplies and facilities as were necessary to develop sound training programs. Approximately one-third of the funds were made available for resident stipends. In recent years, lesser amounts have been necessary for institutional purposes and, consequently, resident stipends have been increased in number and amount. Ultimately it is expected that approximately three-quarters of the training funds will be used for this purpose.

A similar history may be expected in radiology. After a long period in which educational responsibilities have not been met, institutional resources in radiology are small and require substantial augmentation. However, as time passes, increasing amounts of training funds can be diverted to residency stipends, thereby making it possible to close the gap between the demand for radiological service and the availability of trained manpower.

It is difficult to determine precisely the magnitude of the program needed for the training of additional radiological practitioners. A balance must be made between the number of trainees required to substantially correct current manpower shortages within a reasonable period of time and the number of trainees who can actually be attracted to clinical radiology. Every effort should be made to increase the annual number of physicians entering the radiological sciences from the current level of 500 to a level of 800 or more; that is, to attract 300 additional trainees into the field each year. Even though this goal is high, the demand for additional clinical radiologists is great and hence serious attempts should be made to reach it.

At present, the accreditation of a radiologist by the American Board of Radiology requires that he complete three years of approved training in the clinical disciplines of the radiological sciences plus an additional year of training or a year of radiological practice. Therefore, the enrollment of 300 additional trainees each year will require the availability of 900 to 1,200 extra training positions. If quality training is to be furnished, these positions should be largely provided by an expansion of existing training facilities in the nation's large general and university hospitals. Such expansion should be easily possible in most of the institutions without important dilution of the clinical material required for training purposes.

Academic Radiologists: If programs to provide adequate instruction in radiology to all physicians and to train increasing numbers of practicing radiologists are to be successful, it is essential that a sufficient number of teachers be made available in the clinical disciplines of the radiological sciences. However, as pointed out heretofore, serious shortages in academic manpower currently prevail in radiology. It therefore is clear that the development of training programs for radiological teachers must be given the highest possible priority in health planning for the nation.

Currently, there are approximately 800 full-time academic radiologists in the United States.[9] To increase this number substantially over the next decade, it is estimated that 100 additional physicians must enter training in academic radiology each year. Moreover, 400 extra training positions must be established in this nation's university hospitals if these men are to be given four years of training.

The training to be furnished should include broad experience in the fundamentals of radiology. Opportunities should be provided for study in the related basic sciences as well as in the clinical disciplines of the radiological sciences. Also, the trainee early in his career should be given the freedom to pursue his studies without commitment to a particular field of radiological specialization and yet, later on, to have the opportunity to direct his attention to any one of a broad range of special interests. By the development of a comprehensive, well-balanced series of training programs in academic radiology, manpower deficiencies are likely to be corrected in the shortest possible time.

In recent years, modest sums for radiological research training have been made available in a number of special fields by several of the institutes of the Public Health Service. Among these are the National Cancer Institute for training in radiation therapy; the National Heart Institute for training in cardiovascular radiology; and the National Institute of Neurological Diseases and Blindness for training in neuroradiology. These disease-related training

programs, although limited in scope, have been quite worthwhile. They should be continued, unchanged in administration, as important adjuncts to the comprehensive training programs proposed in this report.

In addition to the training programs just cited, the National Institute of General Medical Sciences, with guidance from several advisory groups including this Committee, has recently established a series of programs to provide support for research training in diagnostic roentgenology and nuclear medicine. Although limited in funds, these programs are a partial step in meeting the demand for increased numbers of academic radiologists.

Non-Physician, Professional Training:

One of the most important needs prevailing in the radiological sciences is training support for the development of such non-physician professional personnel as radiological engineers, radiological physicists, radiobiologists, radiochemists and radiological health specialists. Some years ago, the Public Health Service, as a part of its training programs in radiation therapy and cancer control, established support for radiobiologist training. Also, an excellent training program for radiological health specialists has been operated for several years by the Service's Division of Radiological Health. However, specific support for the other types of non-physician specialist training has been either inadequate or lacking. Certainly, the importance of these personnel is sufficiently great that such deficiencies must be corrected. Unless they are, medical progress in the radiological sciences, including efforts to improve equipment and practices from the point of view of radiation protection, will be markedly hampered and American radiologists will become increasingly dependent on the scientists of other countries for the technological advances needed for the development of their profession.

As in training programs for radiologists, the size of the effort to train professional personnel in the supporting disciplines of the radiological sciences may be dictated more by the availability of trainees than by the need for such personnel. It is noteworthy, however, that in spite of the recruitment problems which have occurred in many of the science-related graduate training programs supported by U.S. Government, the universities and colleges associated with the Division of Radiological Health in its training program for radiological health specialists have had, in the main, excellent success in filling student quotas. In view of this, every effort should be made to initiate training programs which will provide as early as possible increasing numbers of such non-physician professional personnel as radiochemists, radiobiologists, radiological physicists as well as radiological engineers. These programs must of course provide the trainee with support sufficient to carry him through three or four years of training to a master's or doctoral degree. From the experience of the Division of Radiological Health, it appears that 100 or more trainees in these disciplines may be recruited each year without difficulty.

Technologist Training:

The need for training of technological personnel has been noted heretofore (see table IV). However, the Committee wishes to make no recommendations concerning the character and scope of this training pending the completion of the studies on technological manpower now being undertaken by the Division of Radiological Health.

Research Grants:

The need for research funds in the radiological sciences perhaps requires little discussion. Over the past two decades, such grants have become such an integral part of the American academic scene that their importance is well recognized. However, the Committee wishes to call attention to the need for applied research and development projects to increase the effectiveness and safety of radiological procedures in the health professions.

Grants for Training and Research and Development Facilities:

The paucity of support for radiological training, research and development to which reference has been repeatedly made in this report has caused a marked deficit in research and training facilities both at the clinical and laboratory levels in most academic departments of radiology. For this reason, a program of con-

struction grants specifically for radiological research and training must be established to correct this deficiency. Indeed, the effectiveness of the training and research grant programs outlined in preceding paragraphs will be limited unless this program is undertaken.

It is difficult to overemphasize the facilities deficit which has been allowed to develop in academic departments of radiology. Without question, it is substantially greater than that experienced by any other major discipline. Unfortunately, its correction will be costly. The characteristics of the radiological sciences are such that their requirements in both space and equipment are unusually expensive. It is perhaps for this reason that corrective measures heretofore have been so inadequate. However, a deficit of this magnitude cannot be allowed to continue in a discipline which, each day, through its dominant role in the provision of quality health care to the public, affects as many people as the radiological sciences do.

TABLE V—Estimated Annual Costs of *Additional* Training and Research Support Needed in the Radiological Sciences

I. Training Grants:		
Predoctoral Training Grants (Physician)		
Institutional Support	$ 1,000,000	
Postdoctoral Training Grants (Physician)		
Radiological Practitioners:		
Stipends for 1,200 trainees	$ 7,200,000	
Institutional support	$ 2,400,000	
Academic Radiologists:		
Stipends for 400 trainees	$ 4,000,000	
Institutional support	$ 2,000,000	
Graduate Training Grants (Non-Physician)		
Stipends for 400 trainees	$ 1,875,000	
Institutional support	$ 625,000	
		$19,100,000
II. Research and Facilities Grants		
Research Grants—		
Additional Support	$10,000,000	
Research and Training Facilities	$10,000,000	
		$20,000,000
		$39,100,000

The estimated cost of the new training and research programs outlined in preceding paragraphs is shown in table V. In the case of the training programs, the data were derived from the number of individuals to be trained each year of the several programs and from information on stipends and related institutional requirements derived from the experience of the Public Health Service. Recommendations for added funds for research are perhaps modest. However, the proposed amount of $10,000,000 per year is intended principally to provide research support leading to improvements in the effectiveness and safety of radiological procedures. As for other research support, the Committee hopes that, as academic radiology is strengthened, it may be able to attract an increasing share of grant support from existing sources. The amounts of money recommended for training and research facilities in the radiological sciences are based on the expectation that, over the next ten years, most and perhaps all of the 100 medical schools which are expected to be in operation by 1975 will require on the average upward of $1,000,000 each. These requirements are high. However, as previously pointed out, the needs are unusually great.

V. PHS Program Development in the Radiological Sciences

(a) The need for a unified administration

Preceding sections of this report have discussed the developing role of the Public Health Service in the radiological sciences. A number of its current activities have been outlined and some of the important unmet needs have been pointed out. Discussions have also centered on some of the programs which the Public Health Service should undertake to resolve the radiological problems now confronting the nation.

In the development of these programs, it is necessary to understand that the radiological sciences comprise a complex series of interdependent disciplines, no one of which stands apart; the problems which affect one have a strong influence on the others. Hence, these

problems are not suitable for solution by a series of uncoordinated efforts. It is not enough to alleviate the problems of diagnostic roentgenology or nuclear medicine without attacking the difficulties prevailing in radiological health, radio-chemistry or radiological engineering; and it is not enough to support radiological health or radiation therapy without giving support to radiobiology or radiological physics. *In brief, program development in the radiological sciences requires a unified effort.*

The uses and control of ionizing radiation in the health professions perhaps constitute the most striking example of the interdependence of the several disciplines comprising the radiological sciences. Advances in diagnostic roentgenology, radiation therapy and nuclear medicine are providing an ever-expanding series of benefits to mankind in the diagnosis and treatment of disease. Yet as valuable as these benefits may be, they are accompanied by increasing risks as exposures to ionizing radiation become greater. Hence, continuous attention must be given to the balance of benefit and risk whenever public health activities relating to the medical applications of ionizing radiation are undertaken. This demands the closest possible relationship between those concerned with developments in clinical radiology and those working in radiological health.

Because of these considerations, the Service should avoid fragmentation of its radiological activities. Programs supporting academic radiology should not be isolated from those pertaining to the control of ionizing radiation; and activities related to the training of professional personnel should not be disassociated from those concerned with the training of technologists. Although sometimes administratively desirable, such fragmentation inevitably leads to serious inconsistencies in program development.

In urging a unified effort in the radiological sciences, the Committee does not wish to imply that there should be no activities relating to these sciences in other divisions and institutes of the Public Health Service. On the contrary, the manner in which the radiological sciences are often involved with other scientific disciplines in the study of biomedical problems requires the development of a number of radiological activities in other agencies. Examples of such activities include the training program in neuroradiology supported by the National Institute of Neurological Diseases and Blindness and the training program in cardiovascular radiology supported by the National Heart Institute.

(b) Strengthening of laboratory and statistical services

As part of its comprehensive effort in the radiological sciences, the Service should develop two important resources: (1) a well-equipped and superbly staffed radiological laboratory to provide expert technical assistance to the health professions and to federal, state and local agencies concerned with the applications and control of ionizing radiation and (2) a well-supported statistical service to collect and analyze a broad range of data useful in the identification and evaluation of radiological problems.

Excellent laboratory resources are a necessary component of the Service's effort to improve the effectiveness with which radiological methods are applied in the health professions, to reduce occupational and environmental exposure from ionizing radiation and to accelerate the rate at which the benefits of the radiological sciences are made available to the public. In the development of these resources, the Service should follow the pattern of its Communicable Disease Center where, in the field of microbiology, laboratory services have been effectively integrated and developed to a high level of excellence. If similar laboratory resources are established for the radiological sciences, the nation will be much closer to a solution to many of its problems arising from the applications and control of ionizing radiation.

The development of substantial statistical resources in the radiological sciences will fill a longstanding need. Many of the radiological problems confronting the nation today may be ascribed to the absence of such resources in the past. For example, current manpower shortages would almost certainly have been detected at a much earlier time if data call-

ing attention to the unusual growth in clinical demand for radiological services had been available. Among the broad range of radiological data which should be under continuous collection and analysis are: (1) appropriate exposure data to identify those radiological installations where radiation control efforts have fallen short of accepted standards; (2) exposure data on selected groups of people to provide information valuable in the epidemiological study of the relationships between radiation dose and biological effects; (3) data on the availability of professional and technical manpower in the radiological sciences; (4) data providing a measure of the growth in demand for radiological services in the health professions; and (5) data which may be used to determine the effectiveness with which public health programs in the radiological sciences are meeting their goals. The systematic collection of these and other data requires resources available only in a major government-supported facility. These resources should be given a high priority in radiological program development.

RESTATEMENT OF RECOMMENDATIONS

In this report the National Advisory Committee on Radiation has made a number of recommendations which it hopes may be helpful to the Surgeon General in meeting the responsibilities of the Public Health Service in the radiological sciences. For convenience, these recommendations are summarized as follows:

1. The Public Health Service should take immediate steps to strengthen its programs in the radiological sciences by unifying their administrative direction. Such action is needed to assure an orderly development of the broad spectrum of radiological activities for which the Service is responsible and to give continuous attention to the balance of benefit and risk in all matters pertaining to the human application of ionizing radiation.

2. The Service should undertake the following training and research and development programs to upgrade the quality of the radiological services which have become such a critical part of medical and dental care and to improve radiation protection practices in the health professions:

(a) a series of training programs: (i) to strengthen radiological instruction of medical students; (ii) to increase the number of academic radiologists in American medical schools; and (iii) to increase the number of practicing radiologists in the United States.

(b) a series of training programs to provide increasing numbers of radiochemists, radiological engineers, radiobiologists, radiological physicists and radiological health specialists.

(c) a series of training programs to provide increasing numbers of technologists in the several disciplines of the radiological sciences.

(d) a series of applied research and development programs to increase the effectiveness and safety with which radiological procedures are employed in the health professions.

(e) a series of programs to provide training and research facilities for academic departments of radiology in American medical schools.

3. The Service should take the initiative in the formulation and promulgation of (a) standards dealing with the qualifications of personnel who operate the x-ray equipment or who use radioactive materials not regulated by the Atomic Energy Commission; (b) design standards for sources containing radium and other radioactive materials that are not reactor byproducts; and (c) standards for the premarketing clearance of x-ray equipment used in the health professions and in industry.

4. The Service should take appropriate action to assure that official health agencies play an increasing prominent role in the appraisal of the health risks associated with the construction and operation of major nuclear facilities.

5. The Service should take immediate steps to strengthen its laboratory and statistical resources in the radiological sciences. These resources are essential components of the PHS

effort to meet the Surgeon General's responsibilities to the nation.

6. If needed, appropriate legislative authority should be sought at the earliest possible time to carry out the foregoing recommendations.

BIBLIOGRAPHY

1. The Control of Radiation Hazards in the United States. A Report to the Surgeon General by the Nat. Adv. Comm. on Rad., Dept. of Health, Educ. and Welf., Pub. Health Service, March 1959.
2. 73 Stat. 688. Atomic Energy Act of 1954, as amended.
3. Radioactive Contamination of the Environment: Public Health Action. A Report to the Surgeon General by the Nat. Adv. Comm. on Rad., Dept. of Health, Educ. and Welf., Pub. Health Service, May, 1962.
4. Public Law 89-97, Social Security Amendments of 1965.
5. Report No. 680, to accompany H.R. 10586. (Depts. of Labor and Health, Educ. and Welf. Supplemental Appropriation Bill, 1966) 89th Congress, 1st Session. Congressional Record, Sept. 3, 1965.
6. Health Statistics: Volume of X-ray Visits, United States, July 1960-June 1961. Series B, No. 38. U.S. Dept. of Health, Educ. and Welf., Pub. Health Service, 1962.
7. Cancer Rates and Risks. PHS Publication No. 1148, U.S. Dept. of Health, Educ. & Welf., Pub. Health Service, 1964.
8. Radioisotopes in Medicine. Stanford Research Institute. Prepared for Office of Isotopes Development, U.S. Atomic Energy Commission. Washington, D.C., 1959.
9. From data supplied by Dept. of Circulation and Records, Am. Med. Assoc., Chicago, Ill.
10. Comm. on Rad. Haz. and Epid. of Malform., Am. Acad. Ped. Pediatrics, 28:676, 1961.
11. Medical Education in the United States, Staff of the Council on Medical Education. J.A.M.A. 190:626, 1964.
12. Coggeshall, L. T. Planning for Medical Progress through Education. A Report Submitted to the Executive Council, Assoc. of Am. Med. Coll. Evanston, 1965.
13. Public Health Service Grants and Awards, Fiscal Year 1964 Funds, Part II, Training Grants, Traineeships, Fellowships and Research Career Program Awards. PHS Publication No. 1233, Part II. U.S. Dept. of Health, Educ. & Welf., Pub. Health Service, 1964.
14. Public Health Service Grants and Awards, Fiscal Year 1964 funds, Part I—Research Grants, PHS Publication No. 1233, Part I. U.S. Dept. of Health, Educ. & Welf., Pub. Health Service, 1964.

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