BECUSE of the considerable complexity of the field of radiation hazards, no one of us is able to explore every aspect in the detail necessary for a complete understanding. I shall discuss details that pertain to public health.

The swift changes in the field of science affect our personal roles. Speaking personally, some years ago I was one of the principal architects in the national community-wide mass x-ray survey program. I now find myself in the present position of discouraging such a special type of effort, except of course for particular population groups where that technique clearly carries more benefit than it does risk.

One theme that is worthy of special mention concerns the role that the physician—today it is the pediatrician in particular—needs to exercise in the important field of radiological health. During the spring of 1960, the Joint Committee on Atomic Energy of the 86th Congress conducted open public hearings for nearly 2 weeks on the subject of radiation protection standards. Some of us present at the Annual Meeting of the Academy of Pediatrics participated in the hearings, as well as in others held earlier. Frequent references were made to the important work of Dr. Friedell's special ad hoc committee of the National Committee on Radiation Protection and Measurements dealing with human population exposure to the radionuclide, strontium-90 (published in Science, 131:3399, 1960); that important document should be read and re-read. At the hearings we tried to represent the profession of medicine and public health. It is worthy of note that ours was only one of many professions to appear. Many disciplines are concerned about the management of problems in this field, with each profession responsible for special aspects falling within its own distinctive province. The field of radiation and child health represents one of the more important problems of the field. Its importance derives from the special significance of ionizing radiation for the health of the young.

RESPONSIBILITIES OF PHYSICIANS

As physicians, pediatricians and practitioners of public health and preventive medicine, we have an important special responsibility for assuring orderly child growth and development. We can take as an axiom that this orderly growth process cannot proceed at its best when, due to a lack of understanding or constructive action, disease is permitted to develop. Potential and active disease states are, of course, numerous, with each one varying in the degree to which it is preventable. When we encounter a new problem like ionizing radiation, having its own special health effects, all practitioners of medicine should try to understand how the problem developed and how its differences from other situations display themselves. Therefore, because I want to emphasize the aspects of public health and preventive medicine, it might help us if we begin by examining the conditions for entry of a health problem into these domains.

First is the public health domain; a problem belongs to this area if it has important aspects best managed through a community approach. These must be aspects of a general problem, in which the capacity of the individual and his physician to manage the problem in its entirety is exceeded. A few examples of procedures which illustrate such problems are: the purification of water, the safe disposal of sewage, the iso-
lation of some communicable diseases in hospitals, and the compulsory regulation of industrial health hazards.

We can cite examples of ionizing radiation problems that meet public health criteria in the form of many individual sources, or some combination of them, which can pose a general threat to community health. Some of these are: 1) testing of weapons, with the attendant possibilities for immediate exposure to some individuals directly engaged in the operations, and, of course, a much larger number through world-wide fall-out resulting in contamination of the general environment; 2) the operation of nuclear reactors, which involves safe management of radioactive discharge products as well as the possibility of accidents; and 3) the use of equipment and procedures entailing ionizing radiation exposure in the healing arts.

Next, let us examine how preventive medicine becomes involved. First of all one needs to note that in this specialty we deal with problems best managed within the individual patient-physician relationship. A public health practitioner generally limits his efforts in this field to assisting the practitioner in treating individual patients wherever he can in meeting his recognized responsibilities to the patient. Public health, of course, has an important interest, because the physician, when he acts as a medical counselor in attempting to promote optimum health of individuals under his care by certain preventive measures, is directly involved in contributing to community health. Immunization procedures designed to prevent certain diseases provide one proof of this. Furthermore, where a disease may not be completely preventable, the individual practitioner will nonetheless attempt to detect the condition—the patient willing—at its earliest manifestation, so that the subsequent course can be most favorably influenced, attended by a corresponding salutary effect on morbidity and mortality. Some of the attempts of public health services to help him do this work well are seen in the efforts to help with physician education; providing certain laboratory services; and, for certain diseases, by even furnishing drugs or immunizing agents without cost to physicians.

The physician himself also practices preventive medicine when he exercises due precautions during the course of various diagnostic and treatment procedures. Some that immediately come to mind are the steps to guard against undesirable reactions from drugs and immunizing agents, the employment of asepsis and antisepsis during surgical procedures, and the addition of a weak solution of silver nitrate, or other effective agent, to the eyes of newborn infants to prevent gonococcal ophthalmia.

This type of work has equal applicability to practices that may entail problems of radiological health. To do this phase well, the physician needs not only a knowledge of the indications for diagnostic and therapeutic radiation but an understanding of the potential hazards of the agents and devices employed. This understanding must be sufficient to enable him to evaluate the use of a particular x-ray exposure in terms of a minimum consistent with the particular diagnostic or therapeutic aim. This concern should encompass not only the patient's interest but should extend beyond the latter to technicians or other personnel in the immediate environment and, of course, to the practitioner himself. Even more than that, he can be expected to advise his patients as well as other members of the community (including officials with an interest) on radiation problems originating in sources that, unlike the aforesaid x-ray, are not under his control. For example, he can intelligently inform parents, or indicate where information can be secured, of the possible effects of radionuclides appearing in milk as a result, let us say, of the testing of weapons.

**EFFECTS OF STRONTIUM-90**

Strontium-90, as you know, is one of the radionuclides originating during the course of atomic fission. Consequently, it appears during the detonation of military weapons
and also in nuclear reactors. It may, in the first case, be distributed for considerable distances, even world-wide in the instance of the larger weapons. In the case of nuclear reactor production, the only real problem thus far has been one of making safe and adequate disposal of it as an unwanted radioactive waste product.

Should strontium-90 gain access to the human body, it can be expected to concentrate in the skeleton, since, like radium, it is a bone seeker. Because strontium-90 has a fairly long half-life of 28 years and a rather energetic beta emission, the skeleton will continue to be irradiated for a considerable period of time once strontium-90 has been deposited there. What it does in terms of clinical effects, and what amounts are needed to produce the effects, are subjects of considerable debate in scientific circles. Some workers feel that the clinical effects would be limited to bone sarcoma, whereas others believe the agent to be leukemogenic as well. Strontium-90 is not generally considered to be a genetic hazard because of its fixation in bone, with the attendant unlikeliness of radiating the genetic apparatus.

At the present time we lack evidence, in the form of human cases, of deleterious effects induced by the presence of strontium-90. All the experimental evidence is from animals, where it has been shown that certain doses, much higher than any experienced by humans or which would be permitted humans if operations are conducted within the framework of current radiation protection guides, have produced bone tumor. The case for leukemia under these experimental conditions has not been conclusively proved. In an attempt, therefore, to relate in some way the possibilities for disease in humans, investigators have turned to the experience of the radium-watch-dial workers, since, as already mentioned, radium and thorium (another naturally occurring radioisotope which is a bone seeker) have been proved to produce malignant bone tumors and nasopharyngeal epidermoid carcinomas.

Some difficulties in analysis are posed here, however, by the fact that there have only been a dozen or so such cases disclosed to date. Nevertheless, these cases have been taken into consideration in attempting to take advantage of all possible evidence, direct or indirect, in estimating the health hazards of strontium-90 in terms of effective dosage. As a result of elaborate calculations that take into account all possible factors, the safe limit on the daily ingestion of strontium-90 has been recommended as 33 μc of strontium-90 per liter, or kilogram, as the case may be. This limit may not be exceeded when considered as an average intake during what is virtually a lifetime period. In other words, it is believed to be safe to exceed this level for limited periods of time, if the average remains within the aforesaid limit, thus insuring that insofar as one can determine, a dose in excess of the safe limit has not accumulated in the skeleton.

The estimate of clinical effects in humans from strontium-90, or other radionuclides, is a statistical estimate and does not represent cases actually identified as due to the influence of the particular agent. The formulation of estimates of this sort not only takes into account the factors already mentioned but also is affected by whether the analyst accepts the linear nonthreshold hypothesis for the expression of effects, a hypothesis that has already been referred to as accepted for genetic effects but which at this time, in deference to the expressed need for the more conservative view, has only been tentatively adopted in the case of somatic conditions.

Public health practitioners are confronted with the obligation to establish and maintain control practices to keep human exposure within these predetermined limits. In regard to unresolved questions to which only further research can contribute better answers than we now have, one still wishes to know how to view the established limits. I think it safe to say that we should regard present limits with a cautious optimism; efforts to remain within them will insure re-
wards in terms of human health protection, regardless of what point on the scale of values the true limit ultimately comes to be set.

Therefore, the Public Health Service's Division of Radiological Health is vigorously prosecuting a program of research and control in this important area. All media, such as air, water, and some foods, particularly milk, have been coming under examination. This part of the program is growing. When the division was first created, in 1958, it conducted milk sampling, at 10 geographic locations, for strontium-90 and other radionuclides such as strontium-89, barium-140, iodine-131 and cesium-137. This program has now been expanded, and is approaching the goal of 60 stations to be in operation by the end of this year. On only one occasion, April, 1959, did a station exceed the 33 μεc limit. This was St. Louis, which, in that month, showed 37.3 μεc/lit. However, the highest average of strontium-90 in our St. Louis milk samples, for any 12-month period, has been about 22 μεc/lit, a level well below that permitted under present standards.

IONIZING RADIATION

A knowledge of the peculiar nature of the high-energy agents considered in ionizing radiation is assumed in the present discussion. These agents differ physically and in terms of their actions on matter. In ordinary chemistry, for example, where we are concerned primarily with changes in the forms of matter, there is less need to emphasize energy exchanges in describing reactions. This is especially true for reactions in biological organisms where ionic rearrangements involve comparatively little transfer of energy, whether it be in normal functioning or in the malfunctioning of disease. It is also true, of course, that both matter and energy are involved in these reactions, with the energy considered in terms of heat stored or heat liberated. However, in some common and important ones, such as hydrolysis, the heat of reaction may be less than 2 calories.

We now understand much about common biochemical operations—the endocrine system, to cite an example, with its contributions to better understanding of the role of insulin and thyroxin, provides a good case in point. When a biological system is exposed to subatomic particles like alpha, beta, or neutron emanations, or to high-energy gamma or beta radiations, we witness an interaction between a high-energy physical system and a low-energy biological system. The consequences of such an interaction are completely different. The alpha particle ejected from a disintegrating radium nucleus, for instance, will deliver 5 to 10 million electron volts of energy along a very short path; on the other hand, ordinary ionic exchanges in living matter involve, on the average, only 5-10 ev/electrons or/molecule. Among other things, this leads to a strange system of dosage units, because the dissipation of so much energy from such a small amount of material, and within such a small amount of material, requires units of a peculiar sort. Thus we are forced to talk about such a unit as the micromicrocurie (one millionth of a millionth of a gram of radium) in order to explain properly the order of exposures.

Therefore—as though the medical sciences have not had enough to do—we now have the added requirement of learning something about modern physics in order to appreciate properly the significance of these new developments. The classical physics that most of us were taught concerned the familiar problems of mechanics, heat, sound, light, and so forth. Although these, as we all have come to know, also exert their peculiar biomedical effects, it is in ways quite different from the ionizing radiations which are part of the subject matter of nuclear physics. It is true, of course, that both groups of physical agents exert their effects over a considerable range of concentrations, although biological systems function within a comparatively narrow segment of the spectra of both.*

* Internal body temperature is maintained at about 98.6°F (37.0°C), with lows or highs around
But here a distinction, important to clinical science, must be noted in these different physical systems. In the medically familiar fields, there is some indicator of the threat: tactile sensations for mechanical pressures; subjective warmth or cold for temperature; auditory sensations for sound vibrations; and so on. In other words, detection of the stimuli by a well-developed sensory system (within a certain range) is possible. For ionizing radiation, however, there is none. A lethal dose can be experienced without any sensory awareness during the time of exposure, or in the latent interval before symptoms and death intervene. And so it is with dosage at any level within the possible range, the smallest and the largest, except that the interval of freedom from symptoms and clinical effects is ordinarily longer in the case of smaller dose levels with their accumulation over considerable periods of time.

This becomes an important point because of two practical problems which it generates: first, the need to rely on special instrumentation and analytic procedures to estimate the degree of exposure to a population or special groups or individuals within it; and, second, the need to secure a good understanding of the health effects over the whole range of possible exposure down to the lowest levels—technically, a very difficult task. These are no longer academic questions.

### Measurement of Radiation Exposure

One result of modern developments in science is a considerable increase in the number of sources of ionizing radiation. Furthermore the full potential, for positive contributions as well as adverse health effects, is yet to be realized. Speaking in terms of the potential for deleterious health effects, our objective in public health and preventive medicine is to keep it no more than "a potential." This is a real problem, because wherever these powerful sources are used, the potential for harm is also present. A "leakage" of such potential—that is, one that can occur in spite of the most stringent controls—must not exceed agreed-on margins of safety. Dr. Crow, as well as other speakers at this special session, has called attention to the need to keep exposure low. Otherwise, society is bound to call the uses into question.

As you have heard, in establishing an adequate margin of safety for normal peacetime activities—one in which we can place complete confidence—each of us will feel more comfortable when there is more experimental evidence to enable a better evaluation of the effects of low doses. Much is known about the effect of high-level exposures presented as whole body irradiation within a short time interval. In these circumstances, some deaths begin to occur at 200 r in humans, followed by an increase in the death rate with increasing dosage until about 600 r is reached, at which level of exposure practically none survive. Exposures of this order can be expected to occur in nuclear war or in certain types of accidents but not in population groups during peacetime. Therefore, our present leading concern is with the lower dosage range, such as single doses below, let us say, 25 r, or in the total dose delivered over longer periods of time.

The principal information concerning these lower dosage levels has been furnished by geneticists in work with animals. Such work indicates that the response to radiation exposure (in terms of new mutations produced) is directly proportional to dose and hence can be described mathematically as a linear relationship. Dr. Crow has given us an able exposition of some of the problems in this field.

Now with regard to somatic effects derived from low doses (principally carcinogenesis and the unsettled question of aging effects), it has been believed, until recently, that these are of a threshold type. This point of view assumes—and there are a number of competent investigators who still
uphold it—the existence of a level below which no clinical effects can be expected in any individual exposed within that lower range. Although this hypothesis has not been disproved, neither does the accumulating experimental evidence confirm it. Consequently, the Federal Radiation Council, which has recently given the question intensive consideration, has made the following declaration:

There are insufficient data to provide a firm basis for evaluating radiation effects for all types and levels of irradiation. There is particular uncertainty with respect to the biological effects at very low doses and low-dose rates. It is not prudent therefore to assume that there is a level of radiation exposure below which there is absolute certainty that no effect may occur. This consideration, in addition to the adoption of the conservative hypothesis of a linear relation between biological effect and the amount of dose, determines our basic approach to the formulation of radiation protection guides.

(If I recall his words correctly, Dr. Friedell has just told us that "the only radiation dose that will do nothing is nothing.")

In the meantime, what guide lines do we follow while continuing to develop the evidence needed to settle the questions involved? If the linear hypothesis be generally true, we need to fall back on some experience to support our use of man-made sources, because statistically there will be risk of some degree at any level above zero dose or exposure. Those responsible for establishing radiation exposure guides believe that, insofar as we know it, our best guide is to be found in the human experience with natural background radiation. This latter arises from radiation sources such as cosmic rays entering the atmosphere from outer space, and terrestrial radiation furnished by elements of the uranium, thorium and actinium series contained in the earth's crust. Its general level varies from place to place on the earth's surface. Speaking of health effects, as far as one is able to ascertain, there has been no gross interference with vital functioning of the human population in areas where the levels are highest. Furthermore, it appears to be a safe assumption that the race, having evolved in a radiation environment of this general order, arrived at an equilibrium and without serious interference to the orderly process of human evolution. Therefore, although our understanding of the radiation problem forces us to view with concern any proposals entailing an increase in the environmental level, scientists feel fairly safe in permitting some low multiple of the average background, if the uses engendering the increase are clearly beneficial to society.

There is little doubt of the medical utility of the oldest man-made source, the x-ray, since procedures entailing its use are among the most important ones now employed in health protection. As matters now stand, the total exposure of the population of the United States from this useful source equals or exceeds the total radiation presented by natural background. This is quite legitimately justified on the basis that the benefits to human life outweigh the risks to the individual for whom the exposure is considered necessary. In explaining the necessity for its judicious use, Dr. Chamberlain and Dr. Hodges have set forth some of the problems in this area and ways in which they can be solved. At any rate, the calculations employed in developing guide lines for exposure have largely concerned themselves with other ionizing radiation sources, although, as you have heard, the x-ray is not omitted from consideration when prescribing measures for general dose reduction to the population.

The Ad Hoc Committee of the National Committee on Radiation Protection and Measurements, in its report (Science, 131: 482, 1960) entitled "Somatic Radiation Dose for the General Population," had this to say concerning the total exposure from industrial, atomic weapons, radioisotopes and other nonmedical sources:

It is not the responsibility of this Ad Hoc Committee to recommend specific levels of maximum permissible dose to the population. It hopes that as more data become available, both as to benefits and risks, a maximum permissible dose representing a proper balance between these [specific levels of maximum permissible dose to the population] can
be found. Meanwhile, it believes that the maximum permissible dose of man-made radiation (excluding medical and dental sources) should not be substantially higher than the background level of natural radiation without a careful examination of the reasons for higher values. For this purpose, it may be convenient to take the background level arbitrarily to be 100 millirrem per year.

This appears to mean that—remembering to exclude x-rays in the healing arts—we might add an increment of exposure from proved beneficial sources to a degree equal to natural background but that any activities which entail increases beyond that must be viewed with concern. Subsequent work may prove this too stringent a requirement, but there seems little choice at present, since a misjudgment of the true state of affairs in a direction of diminished safety would be followed by proportionately adverse effects.

**Effects of Radiation on Child Health**

Now, because we are concerned with the effect of ionizing radiation on the child, what is there about that situation that might be regarded as significant? In preparation for an answer, we can say first that radiological science has rather firmly established the fact that young, and hence more actively growing tissues, are more affected by ionizing radiation than the same tissues of the adult. Experimental work has shown this in mice and rats exposed under various conditions. Case histories have been presented involving congenitally malformed progeny of women exposed to therapeutic doses of radium and x-rays.

It is of interest that adult tissues, such as those occurring in the hematopoietic and gastrointestinal systems, have also been disclosed as more radio-sensitive than others. This differential radiosensitivity has been, in part, explained as a function of mitotic activity.

The increase in radiological health research in recent years, especially through animal experimentation, is developing a growing body of knowledge concerning the various types of harmful effects as related to conditions of exposure, age, species, sex, etc. The report of the United Nations Scientific Committee on effects of ionizing radiation, and the recent report of the Federal Radiation Council offer useful summaries on this work.

A number of interesting observations are disclosed when we examine the evidence afforded by studies of the human population, concerning deleterious effects on children exposed to ionizing radiation.

Let us start with the problem of leukemia. To begin with, it should be noted that, epidemiologically speaking, the general question of leukemia is somewhat of a puzzle. Lea and Abatt, for example, during the course of their investigation of the apparent increase in deaths from the disease in England and Wales between 1911-1955, experienced considerable difficulty in establishing the true incidence of this disorder. When they compared the incidence rates of leukemia in 1911 to 1915 and 1951 to 1955, the latter period showed a rate 4.4 times as great in both males and females. The most marked increase was found in infancy. At first, it was thought that an increased availability of hematologic examinations, or the introduction of the National Health Service in Great Britain during 1947, might explain some of the increase. However, the increased rate in 1941 to 1945, immediately preceding establishment of the National Health Service, was found only in the 11-19-year and 30-39-year age groups. Furthermore, the curve did not flatten for the early 1950's as one might expect if the lack of coverage with specific diagnostic aids had been a factor during the earlier periods. The increase was still evident for 1956.

In discussing the epidemiologic approach to questions of this nature, Gilliam makes a distinction between descriptive and determinative epidemiology. In the direct descriptive method, population groups are characterized on the basis of the presence or the absence of a specific disease-causing factor under investigation. This type of study limits its conclusions in terms of such general factors as age, sex, race and resi-
idence. On the basis of these broad categories, the descriptive method emphasizes specific differences between those with and those without the disease. Gilliam points out that demonstrations of association are not equivalent to proof of causation.

Hempelmann has listed three limitations of the epidemiologic approach to radiation-induced effects: sample size; the interval between exposure and time of study; and the fixed character of the experimental design presented, e.g., inadequate recording of dose or imperfect equivalence of the controls with the index cases.

Buck has attempted to quantitate the relationships between sample size and dose documentation by estimating the sample size necessary to prove a statistically valid increase in leukemia. From reports concerning incidence phenomena, she calculated, for doses accumulated from birth to the age of 34 years, that the minimum number of person-years needed for analysis of the 35-to-44-year age group ranges from 6,000,000 persons-years for 5 r, to 10,000 person-years for 200 r exposure.

Next, certain specific studies attempting to relate effects to dose give us some rough idea of the adequacy of dose-response relations.

The most recent of these concerns the study of the Japanese populations exposed to nuclear bombs at Hiroshima and Nagasaki. This has already shown that the type of leukemia found in each age group is similar to the spontaneous sort. Furthermore, the increase of acute lymphatic leukemia in children under 10 years, especially in males, is pronounced. The latent interval seems to span a period of 4 to 8 years. The curve of dose-response shows a linear relationship related to the center of explosion up to 1,600 meters. However, problems of shielding, location of population, type of weapon, and the proportions of radiation complicate these dose calculations. The linear relationship seems to fit where doses of 50 to 100 rad or more of whole-body exposure were experienced. If a threshold exists, the authors believe it is almost certainly below this 50 to 100 rad level.

The well-known work of Simpson and Hempelmann, who studied children subjected to therapeutic doses of radiation for thymic enlargement in infancy deserves repetition here. For 1,400 children, 7 cases of leukemia were observed compared to 2.6 expected; 7 cases of thyroid carcinoma were observed instead of an expected 0.6. Comparable figures for untreated siblings disclosed no leukemia or thyroid cancers, although 0.6 and 0.08 could be expected statistically. Considering all cancers, 2.6 were expected, but 17 were observed in the treated groups; whereas, in the untreated groups, just 5 were observed compared to 2.7 expected. Furthermore, 3 of 604 children exposed to doses under 200 r developed leukemia.

In another series the results were somewhat different; 1,564 infants were given x-ray therapy, and 224 of these were treated for thymic enlargement; other indications accounted for the remainder treated. Telephone interviews were conducted with 1,170 of the treated children, as well as with 2,923 untreated siblings. The investigators were unable to establish an increased incidence of leukemia, thyroid carcinoma, or other malignancies in the treated group. Ninety-five percent of the children had received a dose of 150 r, and the remainder received between 75-100 r. One difference in the therapeutic management was that the port size was much smaller, and hence the volume of tissue exposed was less than for the other groups reported by Hempelmann. This illustrates the need for access to information allowing a meticulous description of the details of exposure. In addition, the fact that 163 of the treated group could not be traced contributed another difficulty to the valuation.

In a series of 958 infants treated with x-rays to the thymic region, 867 could be traced; two cases of lymphoblastoma and one of lymphosarcoma were found for a total within the range of statistical probability. However, one child developed thyroid carcinoma, a finding of some signifi-
An analysis of the doses received showed about 250 r (air) for the lymphatic malignancies and about 150 r for the patient who developed thyroid carcinoma.

Rooney and Powell reported 357 cases of thyroid carcinoma in children under 18 years. Of these, 121 had a history of radiation therapy during the course of treatment for nonmalignant conditions involving the neck, pharynx or anterior mediastinum.

The lower ranges in the dose-response curve have been studied in Great Britain and in the United States. The comparatively low doses employed in diagnostic abdominal irradiation during pregnancy were reported in these series to double the child’s risk, insofar as subsequent development of leukemia or other malignancies is concerned. (The dose for pelvimetric examinations has been estimated to range between 2 and 6 r to the whole body of the fetus.)

The cases in Great Britain consisted of English and Welsh children under 10 years of age who died of leukemia or cancer between 1953 and 1955; the controls were matched for age, sex and locality and were otherwise chosen at random from the birth register. The cases in the United States were in children in Louisiana who died of the same diseases; the controls were children of comparable age, race and locale, who died from other causes. In the British study 13.7% of the mothers of the children with leukemia and 7.2% of the mothers of the control children received diagnostic irradiation during pregnancy; in the cases in the United States the corresponding figures were 29.7% and 18.3%.

In analyzing the deaths in Great Britain, it was found that three events were more common in the prenatal period of those who died than was the case in the living; these events were direct fetal irradiation, virus infection of the mother and threatened abortion. In addition, three postnatal events occurred more frequently in the children who died of leukemia than for the others; these were x-ray exposure in infancy, acute pulmonary infections and severe injuries.

Another study revealed an interesting difference in risk, depending on the choice of controls. If the controls were untreated siblings, there was a difference in frequency of abdominal exposure during pregnancy and subsequent leukemia. If an unrelated “closest playmate” was used as a control, there was no difference. It is of interest also that neither Polhemus and Koch, who compared 251 leukemia children with 251 controls hospitalized for nonorthopedic surgical conditions, nor Hempelmann and Murray, in a comparison of 65 leukemic, 65 controls and 175 living siblings, could demonstrate a statistically significant difference in prenatal abdominal exposure of the mothers during the relevant pregnancies. However, the former authors did find a difference that approached a statistical significance at the 0.05 level.

Thus one finds at these low levels of exposure considerable disagreement respecting precise dose-effect relationships.

Finally, in the realm of very, very low levels of exposure, there has been a provocative investigation concerning the relationship between the incidence of congenital malformations (as reported on birth certificates) and the geologic formations where the affected resided. These formations were employed as the basis for classifying areas of the state into “probable” and “unlikely,” depending on the content of naturally occurring radioactive materials, primarily uranium and its daughters. The rates of congenital malformations differed by about 25% on the basis of the “probable” and “unlikely” areas—the “probable” averaging 16.2 per 1,000 live births; the “unlikely” 12.9 per 1,000 live births.

A limited number of external gamma measurements were done in the New York study, and the results for the “probable” and “unlikely” areas were 12.0 and 8 μr/hr respectively. The higher value yields a total exposure of about 0.1 r/yr, assuming continuous exposure. For the sake of comparison, average background of external penetrating radiation for the eastern United States is 10 μr/hr; for a mountain location...
like that at Denver, it is about 30 μr/hr. The maximum permissible industrial exposure is 2,500 μr/hr.\textsuperscript{21}

Content of radium in water was also measured for a few locations in the New York area. With the exception of two locations, no significant variation from the average radium content found in city water supplies could be discerned. (The latter averages about $0.3 \times 10^{-16}$ gm radium/ml water, by the method of Hursh.\textsuperscript{22})

**COMMENT**

In attempting to sum up the results, one detects differences not only in methodology between individual studies concerned with the same problem but also in the conclusions. The imprecision of dose estimates has also been pointed out, a condition which reflects the complicated circumstances of exposure. Although these investigations must be refined still further, we nevertheless need to hazard some judgment of their general significance. In attempting to do so, it would seem that the weight of evidence, allowing for probable corrections, supports the hypothesis that ionizing radiation can be a cause of leukemia and other neoplastic diseases in children. Certainly, it appears that the fetus and infant are more sensitive to radiation exposure than are older persons. In addition, it is likely that the dose-response curve is linear, at least in doses above the neighborhood of 100 r. There is need for additional evidence, however, before one can be certain of the shape of the curve in describing dose-effects below that point.

The Division of Radiological Health, now beginning its third year of operation as a special program of the Public Health Service, has an extensive research program involving studies designed to shed some additional light on matters such as this, because of the special interests and responsibilities of the Public Health Service. These interests and responsibilities concern the population as a whole. Therefore, the Service has a natural interest in the question of the effects of ionizing radiation on that population and the circumstances immediately attending it. This explains why current surveys and investigations concern themselves with the water we drink, the air we breathe, the food and milk we consume, and the amount of radiation received by certain population groups.

In an applied research field such as the one we are discussing here, we rely heavily on an epidemiologic approach, concerned as it is with the phenomena of disease in populations. This approach requires, in the radiological health field, the work of many disciplines, beginning with those most immediately concerned in the investigations, such as physicians, engineers, health physicists, radiochemists and others, who deal with the individuals in the population exposed to radiation and the variables in its environment. Therefore, it must be a team approach. At the same time, fundamental research, including that under extra-mural auspices, is encouraged. It is expected that investigators in these two types of experimental approach will enable a comparison of data and conclusions from time to time for the purpose of enabling new practical applications in the control program and of providing further directional guidance to the work of each.

With these principles in mind, let us consider some of the things the Division is undertaking in order to meet its over-all objectives and responsibilities. There is first the work in medical epidemiology, which includes an investigation into the health status of the offspring of 20,000 patients subjected to x-ray pelvimetry during pregnancy. This study includes matched controls.

Two other surveys centering about the possible effects of medical exposures are also worthy of mention. One of these has already been carried out in cooperation with the National Office of Vital Statistics in an attempt to determine the history of medical and dental x-ray exposure to women during the year immediately preceding the birth of a child. Five hundred birth certificates were selected on a systematic
random basis. The response to a mailed questionnaire requesting information on the exposure of the individuals concerned was excellent. Ninety-eight per cent of the dentists, 96% of the physicians, and 90% of the mothers furnished information. These results are now being analyzed. Of interest in the preliminary analysis has been the finding of abdominal, including pelvic, x-ray exposure in about 9% of the mothers. No attempt was made to determine exposure dose, however, because the circumstances preclude an accurate or complete estimate.

The other survey is one under way in a large metropolitan area attempting to ascertain the frequency and type of exposure to medical sources of radiation. This is being correlated with other work directed toward improving calculations of the absorbed dose to certain critical organs such as gonads and bone marrow from various roentgenographic and fluoroscopic procedures.

Next, a tri-state study of the relationship between malformations and natural environmental radiation is under way. Vital records, hospital records, and special hospitals will provide data on the subject. Sole reliance will not be placed on geologic mapping from which levels of radiation may be inferred, but extensive measurements will also be made of levels of internal and external sources of radiation exposure. Interviews of sample cases and control families will be conducted to determine the possible influence of such other etiologic factors as the occurrence of disease in pregnancy, family history of malformation, etc.

In addition, the human population in communities receiving water from the Animas River in the southwestern part of the United States is under intensive investigation. This is a result of detection of higher-than-normal levels of radium in the drinking water resulting from radioactive wastes discharged by an upstream ore-processing plant. Measurement of radioactivity in typical diets, excreta, and bone samples from autopsies will be carried out in attempting to determine the body burden of internally deposited radioisotopes.

In another area of activity, demographic data and epidemiologic information is being obtained to determine if there has occurred any increase in leukemia, bone sarcoma or other diseases in which radiation may have been a factor. The size of this population is small, and certain difficulties involved in applying measurements made of a few families to an entire population, remain to be solved. This is especially true where internal emitters may be involved.

Finally, the problem of fall-out continues to receive a significant share of the attention of the Division.

The milk and food monitoring programs under way for several years have now been expanded, with the number of such sampling points increased from the original 10 to a total of 59 at the present time. The material collected from each of them is analyzed for several radionuclides, including strontium-90 and iodine-131.

Physicians in the St. Louis and the off-site area in Nevada and Utah are also forwarding bone samples from necropsies of stillborn infants, children, and adults for strontium-90 (and, in some cases, radium).

Along with these activities, the Division cooperates with state health departments in the establishment of state radiological health programs. This work includes cooperative x-ray unit surveys with state and local medical and dental societies. Once these surveys help determine the operating status of the machines, necessary corrections can then be made.

Many other important divisional activities, such as support of training and professional education and special projects with other national agencies and professional societies, are also worthy of consideration.

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CORRECTION
In the July, 1961, issue of Pediatrics, in the article by Weber and Hetznecker, entitled "Radiation and Child Health," page 147, an error appeared. On page 150, column 2, lines 19 and 20, is a phrase that reads "5-10 ev/electron or/molecule"; this should read "5-10 ev/atom or/molecule."
RADIATION AND CHILD HEALTH
Francis J. Weber and W. H. Hetznecker
*Pediatrics* 1961;28;147

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