WORLD HEALTH ORGANIZATION

TECHNICAL REPORT SERIES

No. 155

INTRODUCTION OF RADIATION MEDICINE INTO THE UNDERGRADUATE MEDICAL CURRICULUM

Fifth Report of the Expert Committee on Professional and Technical Education of Medical and Auxiliary Personnel

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WORLD HEALTH ORGANIZATION

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GENEVA

1958

EXPERT COMMITTEE
ON PROFESSIONAL AND TECHNICAL EDUCATION OF MEDICAL AND AUXILIARY PERSONNEL

Geneva, 25-30 November 1957

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This report was originally issued in mimeographed form as document WHO/Educ/94.

PRINTED IN SWITZERLAND

Wld Hlth Org. techn. Rep. Ser., 1958, **155**

INTRODUCTION OF RADIATION MEDICINE INTO THE UNDERGRADUATE MEDICAL CURRICULUM

Fifth Report *
of the Expert Committee on Professional and Technical Education of Medical and Auxiliary Personnel

The WHO Expert Committee on Professional and Technical Education of Medical and Auxiliary Personnel met in Geneva from 25 to 30 November 1957. Professor V. R. Khanolkar was elected Chairman; Professor K. Fellinger, Vice-Chairman; and Professor G. Payling Wright, Rapporteur.

The meeting was opened by the Director-General, who drew the Committee's attention to the increasing world-wide interest in the widening applications of atomic energy. He felt that, in view of the scale of these developments, greater attention would have to be given to relevant problems in medical education in general and in undergraduate training in particular. However, at the same time he also stressed that any additions to the already heavy undergraduate curriculum should only be suggested after very careful consideration.

The Committee then proceeded to examine its terms of reference and considered it necessary to give a clearer idea of the general field of interest on which it was called upon to express its recommendations than the short title of its report could convey. In view of the broad range of medical and paramedical questions that might conceivably be regarded as apper-

* The Executive Board, at its twenty-second session, adopted the following resolution:
The Executive Board

1. NOTES the fifth report of the Expert Committee on Professional and Technical Education of Medical and Auxiliary Personnel (Introduction of radiation medicine into the undergraduate medical curriculum);

2. THANKS the members of the Committee for their work; and

3. AUTHORIZES publication of the report.

(Resolution EB22.R30, *Off. Rec. Wld Hlth Org.*, 1958, **88**, 12) taining to " radiation medicine ", it was felt to be desirable that the Committee's activities should be suitably delimited—namely, to the seeking of means and methods of introducing the theories and medical applications of *ionizing radiations* into the undergraduate curriculum in a more comprehensive and co-ordinated manner than formerly. It was to this field of interest, therefore, itself not narrow but with many ramifications throughout all aspects of medical education, that the Committee addressed itself.

1. MEDICINE IN THE ATOMIC AGE

Within the last few years, it has grown increasingly apparent that mere occasional references to the potentially pathogenic effects of ionizing radiations no longer suffice for the education of a medical practitioner who is to pass his professional life in the era of atomic energy. Yet so extensive is the range and content of the present medical curriculum, that any attempt to enlarge it with further material should only be made after the importance of the proposed addition has been closely scrutinized. For an inevitable consequence of increasing specialization among teachers of medicine is an urge—which often reaches missionary fervour—to impart to their students some portion of the large body of knowledge that they have found so satisfying intellectually and have spent so many years in making peculiarly their own. The educator who takes a broad conspectus of the medical course as a whole, however, must seek to reach some practical compromise. While he must clearly go a certain distance to meet the wishes of the specialist, he must do his best to preserve the balance of the already weighty curriculum and to protect—and this is not the least of his tasks—the students from demands that, even in the case of the ablest of them, may prove detrimental to their future intellectual development.

Before entering upon a detailed review of the possible means by which the study of radiation medicine and pathology may with advantage be integrated with cognate subjects in the future medical course, the Committee therefore wishes to make a few general remarks on the principles which should guide educators in a branch of learning that not only has very wide ramifications today but is also enlarging with unprecedented rapidity. It is transparently clear that within the few short years of a medical education, we can only hope to cover a small fraction of the vast factual content of medicine. All that can reasonably be done is to help and encourage students to train themselves in the methodical collection of evidence and in the extraction of warrantable inferences from it. At the same time we can promote this education by communicating facts and theories that have been selected primarily for their probable value to the student in later professional life. How this larger question should be approached is not within the limited scope of the present Committee, which is already acutely aware of the steadily increasing burden being placed on the shoulders of medical students and of the imperative need for some radical revision of the content of certain subjects in the curriculum that have hitherto been regarded as traditional.

It is with a full sense of its responsibility in this matter that the Committee has recommended the inclusion of further material in the curriculum. The era in which atomic reactors will be increasingly employed as sources of power is only beginning, and the medical profession—quite irrespective of its wishes in the matter—is being brought abruptly face to face with new hazards as well as with new potentialities. Many undergraduates now in medical schools will pass their thirty or forty years of professional life in a world in which nuclear energy will come more and more to replace the hitherto conventional forms of power. Furthermore, the science of medicine will, at a steadily increasing rate, incorporate the vast body of knowledge brought forward from the application of radioisotopes and ionizing radiation to biological problems. While it is imperative, therefore, that medical undergraduates be made familiar with these newer concepts and their current place in present-day medicine, such students must also be equipped with a foundation of basic theoretical knowledge upon which they can build effectively in the future. These considerations were prominently in the mind of the Committee throughout its deliberations, as indeed they must engross the thoughts of all who are interested in the furtherance of medical education.

It early became apparent that the administrative nomenclature of medical school and hospital departments varied widely as between countries, so that it became necessary to employ brief descriptions of responsibilities, common to all or most of these institutions, rather than to use denominations which might well give rise to misapprehensions. In the remainder of this report such a course has been followed in order to avoid the ambiguities of differing nomenclatures.

2. " PRELIMINARY ", " PRE-CLINICAL " AND " CLINICAL " PERIODS IN MEDICAL EDUCATION

In order to define the various successive phases of the medical curriculum, as well as in the interests of making recommendations readily applicable to differing national systems of medical education, the following terms have been employed for the designation of the major subdivisions :

(*a*) *Preliminary education.* This is usually undertaken in the later stages of secondary education, before the student enters institutions for professional training, and in itself ordinarily possesses no distinctively vocational character.

(*b*) *Pre-clinical period.* The courses forming this part of the professional curriculum are followed either wholly within the medical school itself or partly in some science faculty, as the case may be. The first year of the pre-clinical period, which usually lasts three or four years, is generally set aside for the study of physics, chemistry and biology. In all three sciences it is becoming customary to orient the subject-matter towards those aspects that bear importantly upon subsequent medical training. The remaining " pre-clinical sciences "—anatomy, physiology, biochemistry, pharmacology, etc.—are already directed towards the preparation of the students for their subsequent clinical studies.

(*c*) *Clinical period.* In the earlier part of this period, which usually extends over three or four years, the student receives further scientific training by completing courses in pathology, microbiology and immunology. In the later and more prolonged part, he receives instruction in clinical subjects and often participates with varying degrees of responsibility in the immediate care of patients.

2.1 Scientific education in the preliminary period

The education of most students whose inclinations lead them later to seek a career in medicine generally becomes increasingly scientific in character as secondary-school or college life draws near its end. The Committee felt that in most instances this education in physics and chemistry, while of a general character, was sufficient, if supplemented by appropriate further work in these subjects during the pre-clinical period, for the purpose of understanding those branches of radiation medicine which students would be likely to encounter during their undergraduate training.

The Committee also felt that the standard of mathematics now ordinarily attained in some countries was adequate ; in others, further efforts should be made to improve the general level of preliminary mathematical and scientific education. In mathematics it is desirable that the medical student should have acquired the ability to employ simple algebraic equations of second degree, exponentials, and logarithms and to undertake plane and solid mensuration. He or she should also possess sufficient understanding of trigonometry and of the differential and integral calculus for the comprehension of such mathematical conceptions should they be presented in scientific writings. With most undergraduate students all the necessary concepts of radiation physics could be conveyed without recourse to mathematics of a more advanced standard.

It was also agreed that some acquaintance with the ideas of probability and statistical analysis were important for the comprehension of radiation physics, as indeed they were also valuable in other branches of medical science and in clinical work.

2.2 The education of the student during the pre-clinical period

2.2.1 *Physics*

2.2.1.1 *General survey*

The recent advances in nuclear physics are among the most revolutionary developments in thought that have been experienced by our generation, and a general acquaintance with them must therefore form an essential part of the education of every cultured person. In many countries, knowledge of this kind is now widely spread, and the high standard of popular books and periodicals devoted to the subject, as regards both accuracy of matter and clarity of exposition, has done much to bring about this improvement. Indeed, any educated person today who wishes to keep informed of current advances in the physical and biological sciences has an almost embarrassingly large number of such publications—many by authors of high scientific standing—from which to select. Valuable though this popularization of science may be, however, the student of medicine who requires to have a grasp of the numerous biological problems that result from exposure to radiation of various kinds needs a foundation in physics that is both more formal and more selective.

The early systematic scientific education of medical students, both at school and during the first years at university, now includes courses in physics in which many aspects of the subject are covered in much the same degree of detail. In the past, the branches presented during the " preliminary " period have included all the classical divisions of physics—mechanics, the properties of matter, heat, light, sound, electricity and magnetism. In the curricula of secondary schools, in which the pupils, although already interested in scientific subjects, are often still uncertain as to the particular career in science or engineering that they hope later to adopt, it is necessary to present all these divisions of physics with more or less equal stress. But once the pupil has decided to study medicine and—as happens in many instances—has already entered a medical school, the relative emphasis attached to these subjects should be changed, and, in particular, the study of electrical and atomic nuclear phenomena in their many forms should be accorded special attention. Moreover, such an altered emphasis has noteworthy educational advantages, for it should not be overlooked that most medical students are at heart more strongly inclined towards the biological sciences ; it follows, therefore, that such a biophysical accentuation takes advantage of that emotional reinforcement of the learning processes to which all educators attach great significance.

It is now generally accepted that in any branch of natural science there can be no proper education without some first-hand practical experience of the subject-matter of the discipline, and this belief is as valid for students in the medical as for those in the scientific faculty. In many aspects of medical physics, this experience can be obtained within the limits of the institution's own laboratories and ancillary departments, for the apparatus and materials needed are of a size and cost which can reasonably be provided from the resources of such a department's budget. But with radiation physics, the scale and nature of the apparatus now used is often larger and more elaborate than it was even a few years ago, and may well prove beyond the range of equipment ordinarily available in medical-school laboratories. There can be no question that many of the better students, especially those whose abilities and interests are likely to take them later into the ranks of investigators rather than those of practitioners, would have their horizon greatly widened if they were able to see such larger equipment in reality, and preferably in action, rather than merely in the illustrations of their textbooks. In the past, a regrettable isolation has often separated the students in the medical faculty from their contemporaries in the other scientific departments of the university, and this has sometimes had the unfortunate result that senior men engaged in research and teaching in the more advanced fields of physics and chemistry have undesirably underrated the abilities of medical students in general and have relegated their tuition to junior colleagues. That a relationship between teacher and taught which originates in this way should frequently engender an undesirable atmosphere—especially among young and impressionable students during their first experience of university life—is quite understandable, and there are grounds for believing that a certain lack of sympathy towards the basic sciences which can often be encountered in older medical practitioners represents the latent reciprocation of this early uncongenial association. Today, fortunately, a larger number of the senior teachers of physics and chemistry at universities—perhaps through a greater sense of social responsibility—are prepared to co-operate more cordially with their colleagues in medical schools, and in most instances where this more liberal attitude has appeared, those responsible for the education of medical students have responded cordially to the opportunity. For it is only through the kind collaboration of those in charge of larger physics laboratories that such apparatus as that effecting particle acceleration, isotope preparation and micro-wave emission can be seen in operation. This latter form of radiation, although not belonging to the category of ionizing radiations, should not be overlooked in this connexion, for although at present microwaves are of limited significance in human pathology, they might well attain much greater importance in the not too distant future should equipment with this form of emission for the transmission of power be developed on a commercial scale.

It is important here to consider very briefly those aspects of the physics of radiation that should be taught to the medical student and the times at which such studies should best be undertaken. The fundamental portion of this instruction will naturally have been given to him by professional physicists during his preliminary and pre-clinical scientific education. But since several years will usually have elapsed between his physics and general pathology courses, it is essential that at some stage during the clinical period these fundamental concepts should again be reviewed and appropriately amplified. Naturally, in such a revision, stress would again be placed more particularly on those aspects which have a close bearing upon the biophysical properties of radiations. So far as ionizing radiations are concerned—and these are much the most important of the radiations which come to the attention of pathologists—, it is such properties as the density of ionization that they produce along their pathways and the depth to which they can penetrate various kinds of tissue which need particular emphasis. In such a review, both electromagnetic and particulate radiation must be considered, together with the various ways in which they may be produced and directed from both high voltage electrical apparatus and the many different types of radioactive isotopes. Moreover, although it is to alpha and beta particles that living tissues are likely to be exposed at the present time, it is clear that, in the near future, protons, neutrons, and perhaps other types of particle, may come into more general use in therapeutics. The basic facts about the interactions of the various types of ionizing radiation with matter should also be incorporated in such a survey, particularly so because such knowledge is essential for an understanding of the different conceptions of " dosage ". Such a review of the fundamentals of radiation physics as that outlined should adopt a forward look as well as concern itself with features directly connected with present-day considerations and practice.

2.2.1.2 *Synopsis of recommended contents of a course*

Having surveyed the various aspects of physics connected with radiation medicine which should be covered during the pre-clinical period, the Committee considered that a useful purpose might be served by the submission of a brief summary of what in its opinion were the most important topics that should be included. These are enumerated briefly in the following schedule. The Committee also considered that the introduction of the student to the physical background of radiation medicine should not be wholly theoretical but should as far as possible contain elements of practical instruction. With this in view, it has set out in an annex (see page 22) a list of demonstrations and experiments, some of which might well find a place at various times in the pre-clinical and clinical periods.

SCHEDULE OF TOPICS FOR A PRE-CLINICAL COURSE IN PHYSICS

(1) The nature of radiations, and their relation to the structure of matter, including the electromagnetic spectrum and particulate radiation.

(2) Physical, chemical and biological effects of radiations, with particular reference to their technical applications in medicine and their injurious effects on somatic and germ cells.

(3) Detection and measurement of radiation; instruments and units.

(4) Natural sources of radiation: internal and external.

(5) Artificial sources of radiation:

(*a*) apparatus for the emission of ionizing radiation

(*b*) radioactive isotopes.

(6) Chemical properties of some elements with important radioactive isotopes, such as germanium, rubidium, strontium, xenon and caesium, whose stable isotopes are unfamiliar in biochemistry.

(7) The principal applications of radiations in biology and medicine.

(8) The more important radiation hazards; aspects of protection and prevention.

Instruction of the kind summarized above should be given in the main by one or more members of the staff of the medical school's department of physics,[1] though in certain limited aspects this would require co-ordination with, or fortification by, members of the departments of biology and chemistry where genetical or biochemical questions were concerned.

2.2.2 *The biological sciences*

2.2.2.1 *Genetics*

The Committee felt that the main principles of genetics should be taught as a branch of science at some stage during the pre-clinical curriculum. It would be desirable if some elementary principles of cytology and relevant techniques were introduced at this stage. In some medical schools these subjects are at present associated with biology or physiology, in others, with embryology. The position of this study in the curriculum should be

[1] It was made clear to the Committee that there was no name already in widespread current use with which to designate a physics department of the kind envisaged. The names " Biophysics ", " Medical Physics ", " Radiation Physics ", " Actinophysics " and " Physics as applied to Medicine " were proposed, but none met with the unanimous approval of the Committee. Under the circumstances, it appeared best to describe what should be the general duties of such a department and leave its name to local decision. The duties in question might be: to review the basic principles of physics that had been taught to the student during the preliminary period, and to apply this knowledge, with particular emphasis on the uses of electricity and ionizing radiations, in the various fields of clinical medicine and its basic sciences.

regarded more as a matter of administration than of principle, and should be left to the discretion of the school.

2.2.2.2 *Physiology and biochemistry*

The employment of isotopes as tools for research in these sciences is now firmly established. It may be confidently expected, therefore, that the student will obtain, to an increasing extent, first-hand experience of their potential uses during his physiology and biochemistry courses, through meeting with practical examples of their employment in simple experiments. While such extensions of the applications of isotopes in medical education were welcomed by the Committee, it felt that this knowledge could only be communicated effectively if every teacher in the pre-clinical period endeavoured to incorporate tuition in the applications of isotopes and radiations into his own personal teaching and not seek dependence in this respect upon some deputizing specialist member of the department of physics. At the same time, it was appreciated that the employment of such materials and agents in the teaching of the medical student was not wholly devoid of risk and that some measure of advice and supervision on the part of experienced radiation physicists was required.

2.3 The education of the student in the clinical period

2.3.1 *General survey*

Once the student has acquired some knowledge of the various forms of radiation that are of significance in pathology, he sould receive some instruction about the units currently employed to measure their intensities in both physical and biophysical terms. These latter terms are especially important, for with his primary interest directed to the potentially injurious effects of ionizing radiations on living structures, the medical student is particularly concerned with the more recently developed derivatives of the curie and the roentgen that have been devised to meet the needs of radiation biologists. Moreover, these concepts are complicated for him by the diversified nature of the radiation that is often emitted by radioactive isotopes at the time of atomic disintegration. The differences between the physical and the biophysical approaches to the methods for the measurement of intensity are not readily comprehensible at first acquaintance; there is no doubt that the medical student has difficulty in appreciating many of these concepts. The student must somehow be protected from the conceptual shortcomings of past usage in lectures and publications, and be taught to avoid the use of obsolescent terms like "rep". The distinction between the "roentgen" (a unit of exposure) and the "rad" (a unit of absorbed dose) should be clarified and emphasized. The disintegration of unstable nuclides, i.e., their radioactivity (unit "curie"), should not become confused with their radiation (as measured with a meter calibrated in roentgens). The energy in the radiation must be distinguished from its power to ionize. While the concepts of dose, total-body dose, depth dose, etc., belong essentially to clinical radiology, the student should have been so instructed in the pre-clinical years that he will not fall into the errors common among many practitioners today.

Once these rather difficult concepts of the physical units of radiation have been explained, and their distinctive applications in biological systems discussed, the idea of " dosage "—more especially that of the 50 % lethal dose (LD_{50})—for different species of mammal, as well as for various lower forms of life, could appropriately be considered. This at once raises the important issue of the difference in the concept and usage of the term " dose " as employed by radiobiologists from that with which the medical student has been made familiar by physiologists and pharmacologists. For the physician and pharmacologist, a " dose " of a drug is that quantity which is required to produce a desired effect—for example, the amount of a barbiturate that is needed to induce sleep. For the radiobiologist, until now, a " dose " was understood to imply the product of radiation intensity and time, and was evaluated by the number of roentgens delivered in a stated number of minutes. In fact, most radiologists still use that mode of evaluation. The development of the use of radiations on a wider range of wavelengths, and especially those of high energy, together with the fact that the biological effects upon which all clinical applications depend are determined by absorbed energy, has led to a different conception of " doses ", which are now expressed in rads or rems.

The distinction between the various uses of the term " dose " may be rendered clearer by giving an example. Any student who consults the pharmacological literature will find that the LD_{50} of tetanus toxin for a dog is about a million times that for a mouse, but similarly he will find it stated that the LD_{50} for an ionizing radiation, such as X-rays, is almost the same for both species when measured in roentgen units. A confusing paradox emerges which requires clarification if the student is to understand correctly the use of the term " dose " (or more accurately " exposure dose ") used by radiobiologists.

To the medical student, the idea that certain poisons, such as lead, possess a cumulative effect is familiar from his earlier studies in toxicology and pharmacology, so that the concept that ionizing radiations may have additive effects in producing lesions is not intrinsically a strange one. None the less, this potentially dangerous property of these radiations should be clearly pointed out and its importance should be particularly emphasized for all persons who, for various reasons, may suffer minor degrees of exposure over long periods and even, as may happen with some physicians, for much of a professional lifetime. The distressing records of leukaemia in radiologists, as well as in patients irradiated periodically for relief from ankylosing spondylitis, provide a warning that should suffice to deter any medical man from unnecessarily endangering his patients or himself by failure to appreciate this property of cumulation.

2.3.2 *Applications during various portions of the clinical period*

2.3.2.1 *Pathology*

Although this subject is here included under the clinical period, in many medical schools it is administratively a component of the pre-clinical period, together with microbiology and immunology. Such administrative differences, however, are immaterial in the present circumstances.

The wide variations in character and severity of the lesions that may follow exposure to various types of ionizing radiations applied either externally or internally make it necessary to consider the pathological sequelae of irradiation under several headings.

(*a*) *Tissue changes*. The cellular and tissue disturbances that follow irradiation both in man and in experimental animals have been extensively studied, but the methods hitherto applied, while giving a limited insight, still fail fully to disclose the nature of the injuries inflicted upon the vital organelles of the affected cells. None the less, at the same time that the students are studying the fundamental features of inflammation, vascular disturbances, allergic reactions and neoplasia, they should be instructed in the general features of the tissue and cellular changes that can be brought about by ionizing radiations.

(*b*) *The possible sequelae of prolonged local irradiation*. Many of the names of the 169 martyrs to the effects of radiation that were incribed on the memorial at Hamburg to the " Roentgenologists and Radiologists of all Nations ... who gave their lives in the struggle against the diseases of mankind ... " are a lasting and melancholy reminder of the power of ionizing radiations as carcinogenic agents for man. Today, there is a better appreciation of the disregard for precautions often shown by many of the early workers in the then new and little explored field of radiation physics—not to mention a certain critical attitude towards some of hem for ill-judged temerity in continuing to expose themselves under conditions which even then had been clearly demonstrated to be hazardous. The present-day radiologists fully realize these risks, and there is much less likelihood that either their patients or they themselves will now be exposed to an extent that may lead to the induction of a cutaneous neoplasm or leukaemia. But the attention of students must be drawn to the danger, and the moral may be pointed by references to comparatively recent instances of leukaemia and of thyroid cancer which have followed upon what were regarded at the time as permissible therapeutic doses.

Of the mechanisms through which ionizing radiations induce the formation of neoplasms, little can profitably be discussed with the students. The whole question is replete with obscurities, and until a clearer picture has emerged from the present haze of fact and theory, there seems little to be gained by an attempt to review so controversial a subject at what must be a relatively elementary level.

The less serious effects of exposure to X-rays and to certain of the radioactive isotopes—skin erythema, epilation, blisters, pigmentation, and sometimes cutaneous scars and cataracts—will naturally feature importantly in the teaching given in the department of radiology. There is nothing yet known about them that is so distinctive as to make it necessary for the general pathologist to take up these lesions and their pathogenesis as a special case of reaction to a noxious agent; they may well be left, therefore, to discussion by radiologists and clinicians.

(*c*) *The sequelae of whole-body irradiation.* Much of our knowledge of acute radiation sickness in human beings has been derived from studies on the survivors of the two atomic bomb explosions in Japan, but it should be appreciated that any adequate study of the earlier phases of this grave syndrome was much handicapped by the great extent of the devastation, the other types of injury caused by fire and structural collapse, and the relatively long interval that elapsed before teams of expert investigators were transported to the wrecked cities. Such observations as were made, however,[1] provide sufficient evidence that the effects of whole-body irradiation for man resemble closely those that can be obtained experimentally with high doses in dogs and other large mammals.

(*d*) *Internal contamination by radioactive substances.* As an introduction to the problems of internal contamination by radioactive substances, it will be necessary to give an account of the human cases of poisoning by radium. This may be compared with the absorption into the body of other long-lived radioelements such as strontium-90, and it may be pointed out that the maximal permissible doses of many bone-seeking radioelements are calculated by comparison with radium.

It is now apparent from observations and experiments on the effects of diffuse irradiation of the body that different types of cell vary widely in their susceptibilities, and that vulnerability, as Bergonie and Tribondeau pointed out fifty years ago, is usually most pronounced in cells which are in the early phases of mitosis. Indeed, by applying the criterion of " cell death ", it has become possible to classify the various types of somatic cells into three categories—" radiosensitive ", " radioresponsive " and " radioresistant ". It may be of interest here to note that there is a close

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1 For a comprehensive account, see : Oughterson, A. W. & Warren, S., eds. (1956) *Medical effects of the atomic bomb in Japan*, New York, McGraw-Hill.

correspondence between the types of cell included in each of these three groups and those that Bizzozero, from his studies on regenerative capacities, long ago denominated " labile ", " stable " and " permanent " cells. It may well be that the persistence of the cell organelle which is capable of initiating mitosis provides the common link between radiosensitivity and capacity for regeneration. There is no need here to dwell on the grave effects of lethal doses of radiation upon the epithelial cells of the alimentary tract mucosa or upon those of the lymphatic and haematopoietic systems. It is now fully appreciated that the widespread destruction of these cells is the immediate cause of the dehydration and infection that are mainly instrumental in bringing about death within the first week or two of the acute exposure. Sometimes, when the person survives longer, the effects of the irradiation on the bone-marrow become evident through increasing anaemia.

During peace time, and during the course of ordinary civilian practice, exposures of the order of 400 r $\pm$ 100 r—the supposed LD_{50} for man—are rarely, if ever, experienced by human beings, so that apart from their interest in connexion with medical problems of defence, there is little to be gained by reviewing in detail the nature of the various tissue and organ lesions that are to be found after a rapidly fatal dose of a penetrating radiation. Worthy of examination, however, are several different syndromes whose appearance may follow exposure to much smaller doses of such radiations, especially when the latter have been experienced over long periods, for these disturbances provide the evidence of excessive irradiation and furnish the symptoms and signs on which a clinical diagnosis will have to be made. As with the heavy, acute exposures to penetrating radiations, the haematopoietic elements in the bone-marrow prove particularly vulnerable to small, but frequently experienced, doses, so the depression of the normal, physiological, replacement of the circulating blood-cells (as reflected in a granulocytopenia during the earlier stages and by the addition of an anaemia in the later ones) has long been regarded as a serious warning signal.

Although the use of periodic blood examinations of persons in occupations that entail some degree of exposure to ionizing radiations is no longer accepted as possessing precautionary value by experienced radiologists, none the less in industrial applications of radiations the protective measures taken may sometimes be inadequate and patients may come under medical observation for the first time with signs of a haematological nature. It is necessary, therefore, that the student be made aware of this clinical manifestation, though it should be made clear that the responsibility for ensuring that the maximum permissible dose as accepted by the International Commission on Radiological Protection is not exceeded rests with the radiologist and his advisory physicist. It is especially important that attention be drawn to the meaning and implications of the " maximum permissible dose ", and the risks that follow if it is exceeded, and that the dangerous cumulative effects of often repeated small doses should be carefully explained to the medical student. It should be, and usually is, the duty of the senior radiologist in any teaching medical centre to deal with these questions of dosage in specific terms while the student is serving in his department. The task of the pathologist can be no more than to provide a general conspectus, in terms of conventional pathology, of the cell and tissue lesions that may be encountered later if the exposure should much exceed the maximum permissible dose. The best ways in which this overlapping portion of the curriculum could be shared between radiologists and pathologists might well receive careful consideration, for it forms an important nodal point in this aspect of medical education.

2.3.2.2 *Clinical and radiological aspects*

In the view of the Committee, the manifold occasions on which radiations are employed in clinical medicine and surgery, both for diagnosis and treatment, make it highly desirable that a formal organized course of instruction be given to the students under the auspices of the radiological department of the medical school and hospital. Such a course should be thorough, and introduced by a survey of the physics of radiations of a nature that can recall to the student the relevant instruction given to him in his pre-clinical classes in physics, some four or five years earlier. Later in the course the many valuable uses of radiation in medicine and surgery must be reviewed, but at all stages, both in the radiological department and in the clinics, the student should be impressed with the potential hazards that follow from inappropriate use. To some extent, by suitable precautions, the danger to the gonads and other organs may be materially lessened, and the importance of ensuring as much protection as is compatible with the types and numbers of radiographs required for clinical purposes should be firmly impressed upon the students.

In past years, most of the risks from excessive irradiation have been incurred from multiple X-ray examinations and deep X-ray therapy, but more recently a fresh hazard has arisen from the introduction of radioactive isotopes into medical practice. No course of instruction in radiology can now be regarded as complete without reference to the current applications of isotopes in clinical examinations, and the dangers that their use may impose both upon the patient and upon the clinician concerned. It seems likely that before long a great many radioisotopes may be in use, owing to the steady increase over the last few years in the number of clinical diagnostic procedures employing them. Possibly in no other portion of the course in radiology during the clinical period will constant revision of subject-matter be so essential. Much of this knowledge should be acquired practically by the student, however, through seeing isotopes applied in clinical diagnoses by his teachers in the hospital wards.

In view of the frequency with which ionizing radiations are now employed, it is very desirable that some instruction be given the student in the handling of patients who report that they have been exposed to, or fear the sequelae of, ionizing radiations. Under such circumstances, he should be instructed to make careful inquiries as to the probable amount of exposure incurred, perform the necessary blood examinations, and, when satisfied as to the need for further study, refer the case to some institution adequately equipped for diagnosis and treatment. He should be impressed with the need for the careful assessment and recording of any such exposure as well as of the clinical condition both at the time of first examination and later, for it is through the subsequent follow-up observations upon such patients that much needed medical knowledge can be gained. The student must be impressed with the potential importance of any contamination and with the need for promptly obtaining the advice of some physician with special experience, particularly in view of the possibility of subsequent medico-legal developments.

While the Committee was of the opinion that it was no part of its duty to suggest the specialized nature of the training that would be needed to cope with an atomic explosion of great magnitude, it felt that undergraduate medical students should be made aware of the clinical features of heavy and possibly fatal acute radiation syndrome that follows whole-body irradiation. Such aspects as dehydration, shock, blood dyscrasia, burns and infections should receive brief but adequate mention.

2.3.2.3 *The genetic effects of irradiation*

Few scientific questions during the last few years have given greater concern or aroused more apprehension in the intelligent public than the possibility that grave genetic injuries may be caused to future generations by the indiscriminate application of radioactive materials to both civil and military uses. Many people who themselves would have little hesitation in incurring such risks as an individual personal danger view with alarm the augmentation of hereditary defects and diseases—especially those of a mental nature—that any serious increase in the present mutation rate for human beings would inevitably entail. Whereas no damaged somatic cell can survive the individual person, a mutilated germ cell is potentially immortal. There is much in Waddington's remark: "Even if we cannot discover a cure for the ills that we may be inflicting on future generations we ought at least to take trouble to find out so that we can decide how far we shall go in running up biological debts which our descendants will have to pay."

As regards the immediate issue, there can be little doubt among educators that the subject of the possible genetic injuries which may be caused by radiations should come comparatively late in the curriculum. No adequate discussion of such problems can be undertaken without frequent reference to disease states and their etiology, for apprehension as to the effects of ionizing radiation arises mainly from the possibility that it may entail a serious increase in various hereditary abnormalities and diseases. Though it would seem that a suitable short course could best be organized under the auspices of departments of medicine or of pathology, only in exceptional instances could such departments recruit teachers with the necessary training from among their own staffs. In the case of medical schools which possess adequate affiliated departments of biology and biophysics, it might be possible to bring those departments into association in devising such a course. Indeed, in many medical schools the personnel concerned would probably gladly agree to take part in any such combined scheme, for many of the teachers of what are now quite undesirably termed the " pre-medical subjects " would welcome an opportunity for further contact with the training of their former students at this more advanced stage of their education. The integration of the various contributions to a combined course on radiation pathology would obviously require care, and, as has already been pointed out, it would not absolve the clinical teacher from his full share of the work. But given the necessary goodwill between the several participating departments, it could become a very interesting experiment in medical education. It would at least throw down a challenge to the increasing number of pre-clinical teachers who are anxious to establish their belief in the benefits of more collaboration at all stages of the curriculum.

From these considerations the Committee reached the conclusion that a second review of genetics from the somewhat different angle of disease and acquired mutations in human populations should occupy a short period in clinical studies. Here again the nature of the associated departments should be a matter for decision by the school, but it was felt that though the questions necessarily demanded some formal treatment by one clinical department, supplemented, as has already been stated, by teachers of biology and physics, references to the part played by heredity as an etiological agent should, wherever appropriate, be made by all teachers engaged on clinical instruction. This recommendation is supported by the conclusions reached by the WHO Study Group on the Effect of Radiation on Human Heredity.[1] The Committee felt, too, that departments of diagnostic and therapeutic radiology carried an especially heavy responsibility in ensuring that all students passing through medical school be made aware of the genetic hazards of radiation. The dangers are set out in a number of inexpensive official publications, readily available to the students, which describe the comparative risks now believed to be attached

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[1] World Health Organization (1957) *Effect of radiation on human heredity. Report of a study group...*, Geneva, pp. 18-20

to different types of radiation, avoidable and unavoidable, and the circumstances of exposure. An especially strong warning should be given to all students to avoid as much as possible the exposure of children, young persons and, in particular, pregnant women because of the exceptionally high sensitivity of the embryo to penetrating ionizing radiations.

2.3.2.4 *Public health aspects of radiation medicine*

In view of the fourth report of the Expert Committee on Professional and Technical Education of Medical and Auxiliary Personnel, concerned with Post-graduate Training in the Public Health Aspects of Nuclear Energy,[1] it was not felt to be necessary for the present Committee to consider this question at the same high technical level. At the same time, it was believed that the hazards of radiation medicine should receive some attention in the courses known by various titles, of which "Preventive Medicine", "Public Health", "Social Medicine" and "Hygiene" are now widely employed in the curriculum. Consideration should be given to the increasing possibilities of undue exposure to radiation in certain industries, and students should be strongly advised that when they enter practice they should familiarize themselves with the more important technical aspects of those industrial activities that are prosecuted in their neighbourhood, in order to become aware of the possible hazards that such occupations involve.

3. METHODS OF FURTHERING KNOWLEDGE AND INTEREST IN RADIATION MEDICINE AMONG MEDICAL-SCHOOL TEACHERS

The Committee realized very fully that with an aspect of medicine that, in one form or another, occupied almost the whole of the curriculum, it would be highly desirable to enlist the sympathy of all teachers in both the pre-clinical and the clinical courses. It was felt, too, that in many schools the number of teachers who at present might participate in the teaching of radiation medicine was insufficient and that some methods of awakening greater interest in present teachers and promoting specialized training for additional teachers should be sought. The proposals enumerated below were acceptable to the Committee :

(1) The training of younger teachers by the creation of fellowships for study at some suitable institution at home or abroad.

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1 *Wld Hlth Org. techn. Rep. Ser.*, 1958, **154**

(2) The group training of teachers through the establishment of short courses at selected national institutions.

(3) The creation of training centres which might be supported by external bodies that have been active in the international field in the promotion of higher education.

(4) The organization of symposia and seminars for the purpose of bringing together persons interested, or potentially interested, in radiation medicine.

(5) The local organization of " Weeks of Radiation Medicine ", which would entail a combined operation between local and visiting teachers. On these occasions, strong emphasis might be placed upon the uses—and abuses—of ionizing radiations through the demonstration of scientific and clinical examples.

(6) The appointment of visiting professors for limited periods.

(7) The preparation of a suitable small monograph or carefully coordinated series of essays drawing attention to the uses of radiations in many branches of medical work.

4. POSSIBLE METHODS OF OBTAINING INTEGRATION IN THE TEACHING OF RADIATION MEDICINE

It became apparent to the Committee that if the general survey of the problem and its possible solutions were to prove acceptable, it would be essential that some careful integration of the various portions of the courses should be undertaken. Such integration, sometimes termed vertical integration, requires the close and cordial collaboration of all the teachers who make contributions to the course. But since the participation will be unequally divided among them, the Committee felt that the major responsibility would usually fall upon the senior teacher in the department of physics and the senior teacher in the department of radiology. By informal discussion with and approach to their appropriate scientific and clinical colleagues, those two members of the staff would be able to assure a satisfactory measure of continuity throughout the pre-clinical and clinical periods and ensure that no matters of importance were omitted.

The Committee considered, however, that although appropriate formal courses would form the main foundation for this instruction, it would be very desirable if in each pre-clinical or clinical department the teachers endeavoured to incorporate, through their own personal mastery of the relevant material, the applications of isotopes and radiations into their general scheme of instruction.

5. THE TECHNIQUES OF TEACHING RADIATION MEDICINE

The Committee felt that there was a strong case for the introduction of certain newer techniques into the teaching of radiation physics and its applications. Some new types of visual aids could very aptly be introduced to reinforce the more conventional methods of education hitherto employed. Medical students, perhaps because of their lengthy training in biological and anatomical dissection, tend to have " three-dimensional " minds, and advantage might well be taken of this aptitude in devising better methods for their instruction.

The Committee had before it certain proposals, some of which are outlined below, but in a scientific field that is undergoing such rapid developments it is inevitable that improved methods are invented from time to time.

(1) Visual aids :

(*a*) Documentary and animated films

(*b*) Scale models that might help, for example, to relate the lengths of ionization pathways and ionizing densities to such important cellular organelles as genes, chromosomes and mitochondria, as well as to various common virus particles.

(2) Visits to installations at which the student might see relatively elaborate equipment designed for irradiation.

(3) The undertaking of suitable experiments at various stages of the student's pre-clinical and clinical studies (see Annex).

Annex

EXAMPLES OF LABORATORY EXPERIMENTS, DEMONSTRATIONS AND PRACTICAL TRAINING WHICH MAY PROFITABLY BE INCLUDED IN THE UNDERGRADUATE MEDICAL CURRICULUM

Course	*Approximate period*	*Experiments*
Physics	Early pre-clinical period	Use of G-M counter Use of scintillation counter Use of ionization chamber Determination of half-life of an isotope Absorption curves of various types of radiation Photographic effect of radiation Presence of cosmic rays Absorption by various materials Wilson chamber Fluorescence and phosphorescence
Chemistry	Early pre-clinical period	Measurement of reaction velocity by means of radioisotopes Contamination of glassware with radio-isotopes Decontamination by inactive dilution technique Oxidation of Fe^{++} to Fe^{+++} by ionizing radiation (concept of "indirect effect")
Medical statistics	Pre-clinical period	Disintegration rate as a Gaussian frequency curve
Biochemistry	Pre-clinical period	Use of an isotope in a specific tracer experiment in animals Enzyme inactivation by X-rays; dilution effect
Anatomy	Late pre-clinical period	X-rays to demonstrate anatomical facts

Course	*Approximate period*	*Experiments*
Physiology	Pre-clinical period	Haemodynamics (Na^{24}) Thyroid function test (I^{131}) in rats Thyroid ablation (I^{131}) and myxoedema Fluoroscopic demonstration of deglutition, etc.
Histology	Late pre-clinical period	Radioautography (e.g., uptake of I^{131} in chicken embryo)
Genetics and cytology	Pre-clinical period	Demonstration of increased mutation frequency (in *Drosophila* or *Neurospora*) after exposure to X-rays Chromosome breakage and types of chromosomal aberrations induced by ionizing radiations (e.g., meiotic and somatic chromosome damage in *Tradescantia*, suitable animal cells and tumours)
Histopathology	Late pre-clinical or early clinical period	Modifications in cells and tissues following ionizing irradiation (e.g., intestinal epithelium, *Vicia faba*)
Gross pathology or morbid anatomy	Clinical period	Local effects : Erythema Burns Necroses General effects : Effects on bone-marrow and blood-forming organs Effect on intestines Cancer, leukaemia
Radiology	Clinical period	Demonstration of pertinent techniques of fluoroscopy and radiography Dose measurements in ordinary X-ray series

Course	*Approximate period*	*Experiments*
Radiology *(continued)*	Clinical period	Effect of voltage on half-value layer in several materials and on visibility of soft tissues and bone. Demonstration of minimum shadow visible in the chest. Effect of cone and Bucky diaphragm. Disappearance of soft tissue immersed in water
Internal medicine Clinical pathology Isotope laboratory Radiology	Clinical period	G-M measurements Scintillation counters Thyroid function test (thyroid uptake and urinary excretion of I^{131}) Participation in diagnosis with isotopes routinely used in the medical clinic for special purposes: blood volume (serum albumin, I^{131}), red cell life-span (Cr^{51}), etc.
Formal organized course	Late clinical period	Repetition of certain previous experiments Demonstration of nervous system death, intestinal death, bone-marrow death, etc., in rats or mice Demonstration of effect of oxygen removal (*E. coli*) Demonstration of protection by compounds of the cysteine-cysteamine group (mice) Weight changes of various organs following exposure to ionizing radiation Demonstration of the " indirect effect "