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Computerized transverse axial scanning (tomography): Part I. Description of system

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ABSTRACT

This article describes a technique in which X-ray transmission readings are taken through the head at a multitude of angles: from these data, absorption values of the material contained within the head are calculated on a computer and presented as a series of pictures of slices of the cranium. The system is approximately 100 times more sensitive than conventional X-ray systems to such an extent that variations in soft tissues of nearly similar density can be displayed.

For many years past, X-ray techniques have been developed along the same lines, namely the recording on photographic film of the shadow of the object to be viewed. Recently, it has been realized that this is not the most efficient method of utilizing all the information that can be obtained from the X-ray beam. Oldendorf (1961) carried out experiments based on principles similar to those described here, but it was not then fully realized that very high efficiencies could be achieved and so, picture reconstruction techniques were not fully developed.

As the exposure of the patient to X rays must be restricted, there is an upper limit to the number of photons that may be passed through the body during the examination, and so to the amount of information that can be obtained. It is, therefore, of great importance that the method of examination ensures that all the information obtained is fully utilized and interpreted with maximum efficiency.

In the conventional film technique a large proportion of the available information is lost in attempting to portray all the information from a three-dimensional body on a two-dimensional photographic plate, the image superimposing all objects from front to rear. In order that any one internal structure may be seen, it must clearly stand out against the variations of the materials in front and behind it.

The technique to be described divides the head into a series of slices, each being irradiated via its edges; the radiation is confined to the slice and for this reason, unlike conventional X-ray techniques, the information derived from any object within the slice is unaffected by variations in the material on either side of the slice. Data are processed and displayed by digital computer methods.

A report on this work was presented at the April 1972 Annual Congress of the British Institute of Radiology (Ambrose and Hounsfield, 1973). A short account has also appeared in the *New Scientist* (*Technology Review*), 1972.

PRINCIPLES OF THE METHOD

The aim of the system is to produce a series of images by a tomographic method as illustrated in Fig. 1. Each image shown at the bottom of the figure is derived from a particular slice.

In the actual equipment, the patient is scanned by a narrow beam of X rays. The X-ray tube, detectors, and collimators are fixed to a common frame, as shown in Fig. 2, those rays which pass through the head being detected by two collimated sensing devices (scintillation detectors) which always point towards the X-ray source. Both X-ray source and detectors scan across the patient's head linearly taking 160 readings of transmissions through the head as shown in scan 1 on the scanning sequence diagram (Fig. 3). At the end of the scan the scanning system is rotated 1 deg. and the process is repeated, as shown in scans 2 and 3. This continues for 180 deg. when 28,800 (180×160) readings of transmission will have been taken by each detector. These are stored in a disc file for processing by a mini computer. A picture is reconstructed from the data by the following method:

A separate detector measures the intensity of the X-ray source and the readings taken from this can be used to calculate absorption by the material along the X-ray beam path, where

$$\text{Absorption} = \log \frac{\text{Intensity of X rays at source}}{\text{Intensity of X rays at detector}}$$

If the body is divided into a series of small cubes each having a calculable value of absorption, then the sum of the absorption values of the cubes which are contained within the X-ray beam will equal the total absorption of the beam path. Each beam path, therefore, forms one of a series of 28,800 simultaneous equations, in which there are 6,400 variables and, providing that there are more equations than variables, then the values of each cube in the slice can be solved. In short there must be more X-ray readings than picture points.

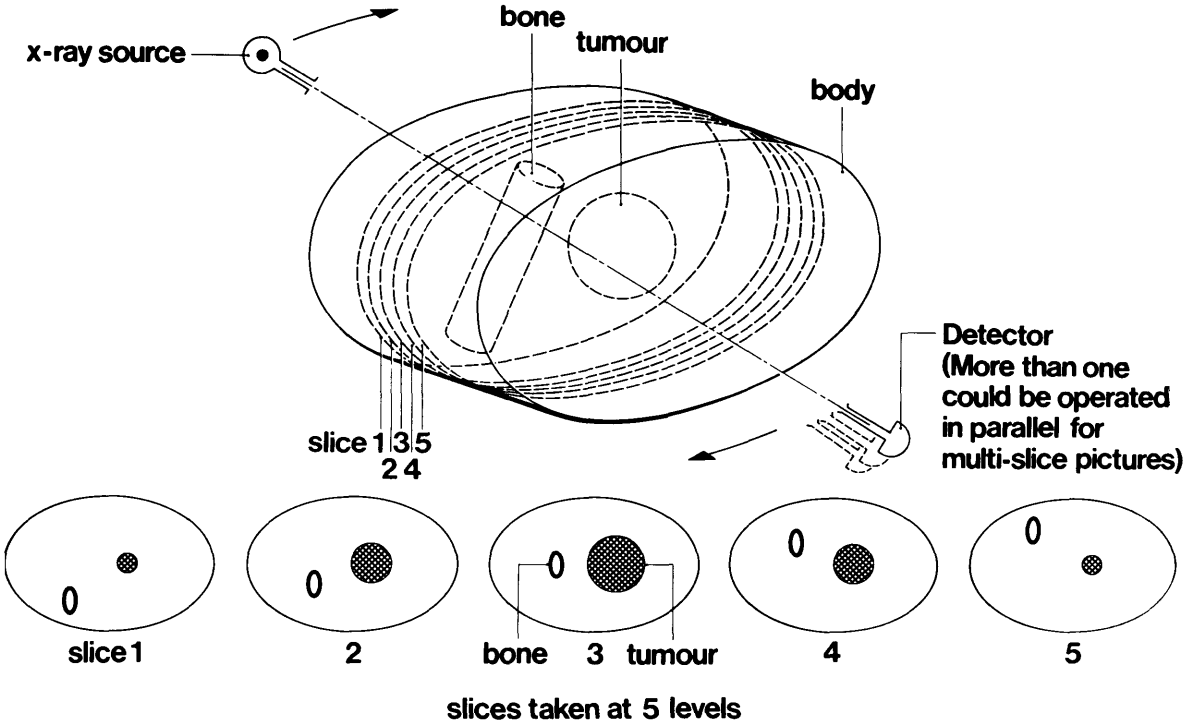

FIG. 1.
Computerized transverse axial techniques on a body containing bone and tumour.

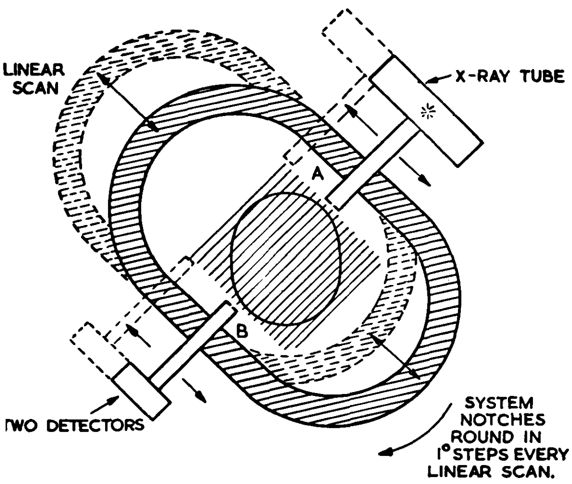

FIG. 2.
Motion of scanning frame and detectors for producing two continuous slices.

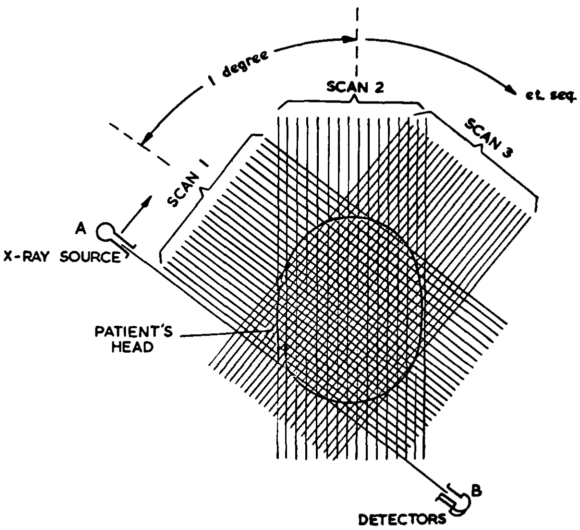

FIG. 3.
Simplified illustration of the scanning sequence.

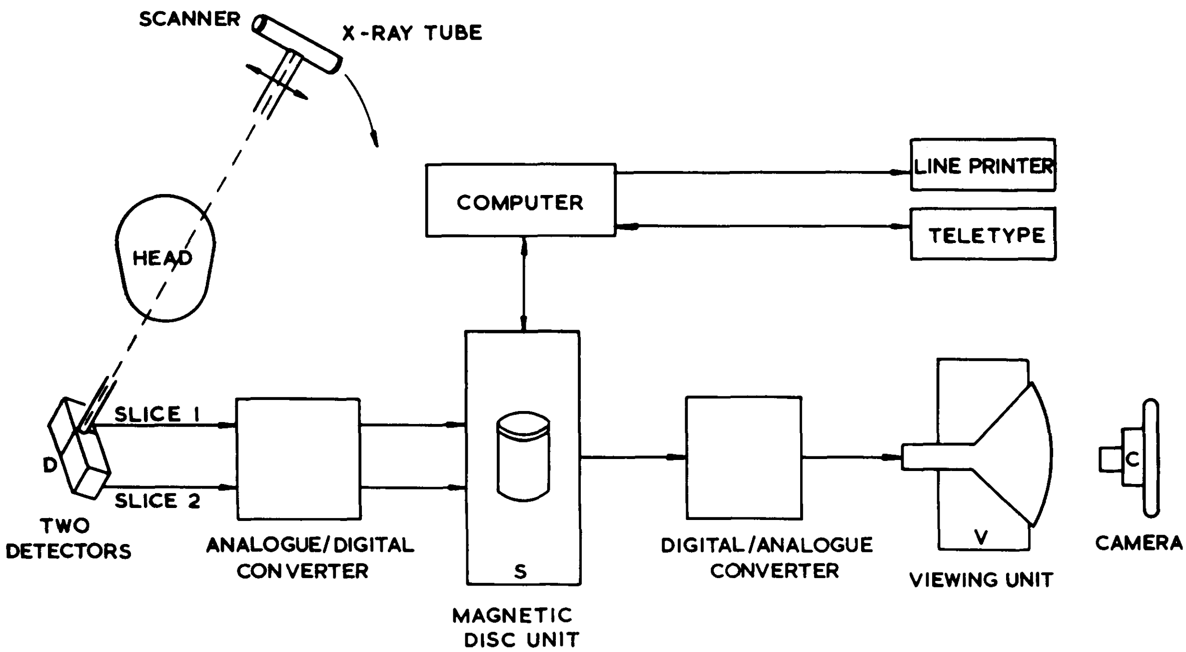

FIG. 4.

Block diagram illustrating how the readings from the two detectors are digitized, stored in a disc unit, processed in the computer and printed out on a line printer. They are also stored in the disc unit as fully processed pictures to be viewed on the viewing unit.

FIG. 5.

Illustration of the patient in position.

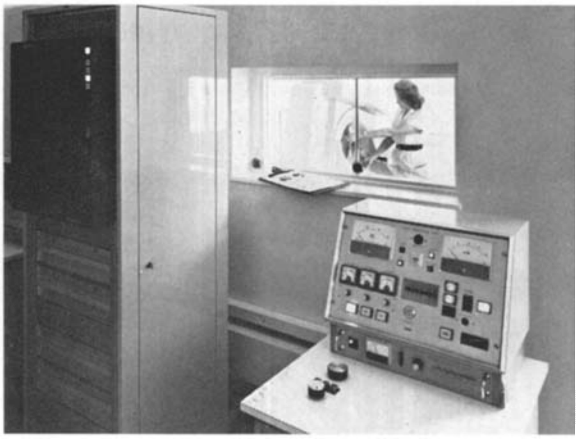

FIG. 6.

X-ray control console.

The picture is built up in the form of an 80×80 matrix of picture points to each of which a numerical value is ascribed. Each of these points indicates the value of the absorption coefficient of the corresponding volume of material in the slice. After appropriate scaling, as explained later in the text, the absolute values of absorption coefficient of various tissues are calculated to an accuracy of $\frac{1}{2}$ per cent. These values are printed out on a line printer or viewed on a cathode ray-tube (Fig. 4).

THE SCANNER UNIT

Figure 5 shows part of the system in use at the Atkinson Morley's Hospital, Wimbledon. The patient's head is placed within a rubber cap in a circular orifice around which the X-ray source and detectors rotate.

The rubber cap forms the front face of a box containing water, and when this is pumped out the rubber cap expands and the patient's head is inserted at the correct angle. The water is then caused to flow back allowing the cap to collapse on the patient's head. Since the sides of the box are parallel, and the air around the head has been replaced by water which is of similar absorption to the head, the variations of transmission through the box during the scan will be considerably less than if the head were to be scanned in air. This reduces the range of the readings from the machine and so eases the calculations required to be made by the computer, thereby increasing the accuracy of the machine.

The control console for the X-ray tube and the patient scan "start" and "stop" mechanism is shown in Fig. 6, and the computer console in Fig. 7. Readings from the scanning unit for one cut are stored on a removable disc pack and processed (five minutes per picture) during the scanning of the following cut. The processor is time shared with the scanner unit, its speed being such that it is able to keep pace with the flow of patients through the scanner unit. This assumes an average of 35 minutes per patient and six pictures are taken during this period. The removable disc pack can store more than 60 pictures any of which can be selected and viewed on the viewing unit (Fig. 8).

Accuracy of Picture Readings

Laboratory measurements (for a tube operated at 120 kV) of water and various body fluids and tissues are shown on the chart (Fig. 9). It can be seen that fat has an absorption coefficient 10 per cent less than water and tissue, on average, a value approximately 3 per cent greater than that of water. Variation of tissue absorption found in the head including the ventricles covers a 4 per cent range. The picture brightness and contrast can be adjusted so that this 4 per cent range, or "window", covers full black to peak white, illustrated in Fig. 9 as "Tone Range". As the absorption coefficient in this range can be measured to an accuracy better than 0·5 per cent, this means that at least eight different levels can be detected within the "window". The height of the "window" can also be adjusted to the level of any

Fig. 7.
Computer console for processing and storing the pictures.

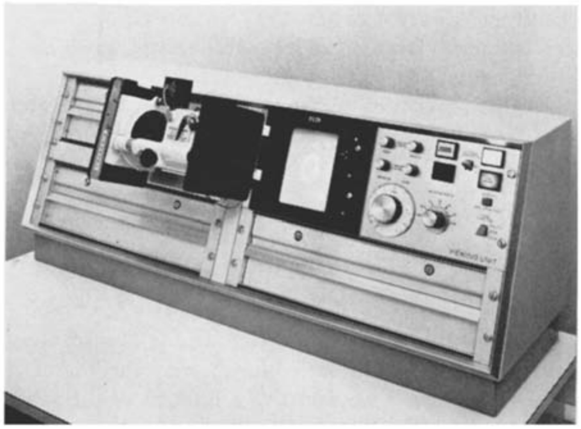

Fig. 8.
Viewing unit and camera.

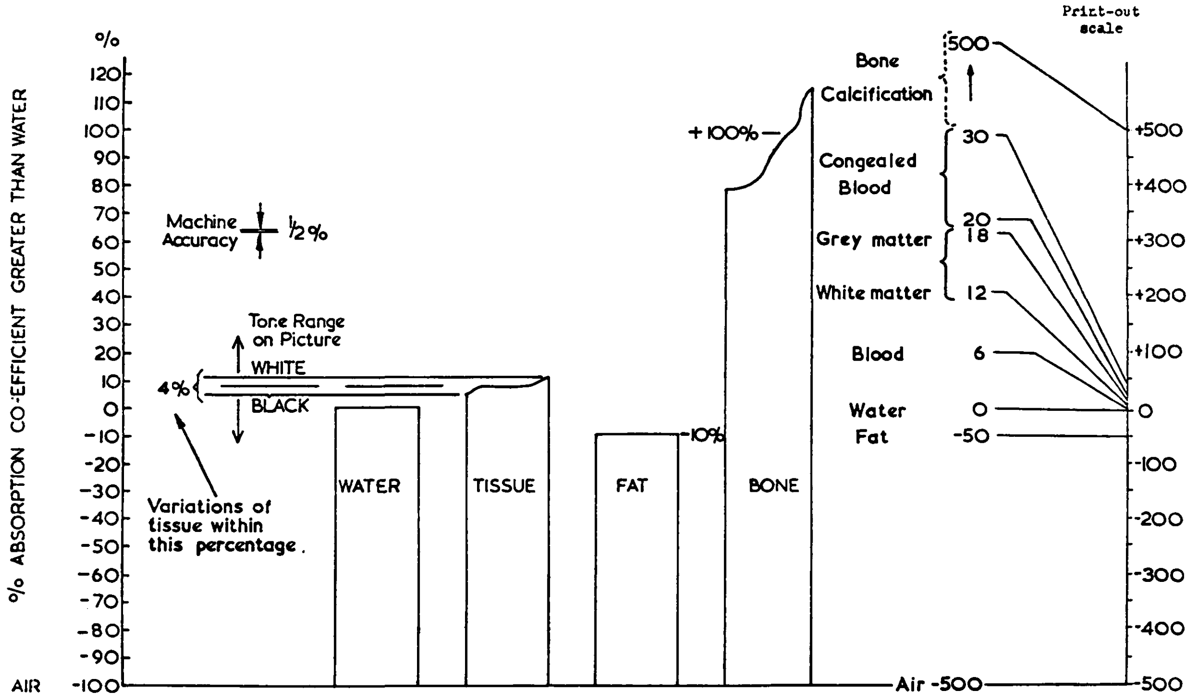

FIG. 9.

Illustration of machine sensitivity. The scale on the right is an arbitrary scale used on the print-out and is related to water = 0, air = 500 units. It can be seen that most materials to be detected fall within 20 units above zero and can be covered by the adjustable 4 per cent "window".

material which is to be viewed. A more convenient scale used on the print-outs (of absorption values) is given on the right where air is shown as −500, water as 0, and bone as approximately +500; this scale is used on the machine.

The pictures shown in Fig. 10 illustrate in practice how the picture changes, similar to a television "contrast" control, when the "window level" control is raised from −20%(−100 units) to +70% (+350 units).

As this scale uses water as a reference (*i.e.* water =0), to obtain the absorption coefficient of any material for the 120 kV X-ray beam, 500 must be added to the readings and multiplied by a factor of 0·19/500, the absorption coefficient of water for this beam being 0·19 cm^{-1}.

DETERMINATION OF ATOMIC NUMBER OF MATERIAL

It is possible to use the machine for determining approximately the atomic number of the material within the slice. Two pictures are taken of the same slice, one at 100 kV and the other at 140 kV. If the scale of one picture is adjusted so that the values of normal tissue are the same on both pictures, then the picture containing material with a high atomic number will have higher values at the corresponding place on the 100 kV picture. One picture can then be subtracted from the other by the computer so that areas containing high atomic numbers can be enhanced. (In practice a contrast medium, sodium iothalamate containing 420 mg of atomic iodine per millilitre (Conray 420) can be readily detected at a concentration of one part in 1,000 by the machine.) For example, tests carried out to date have shown that iodine (Z=53) can be readily distinguished from calcium (Z=20). The scope of this technique is under further investigation at present.

RADIATION DOSE

The skin area irradiated is confined to a narrow band around the edge of each slice and provided the slices do not overlap the skin dose will not increase with the number of slices taken (although the area irradiated will increase). The exposure at the patient's skin is 1·9 R for an examination which provides six tomographic slices covering the whole of the head. This exposure is approximately equivalent to a conventional skull X-ray examination. Two pic-

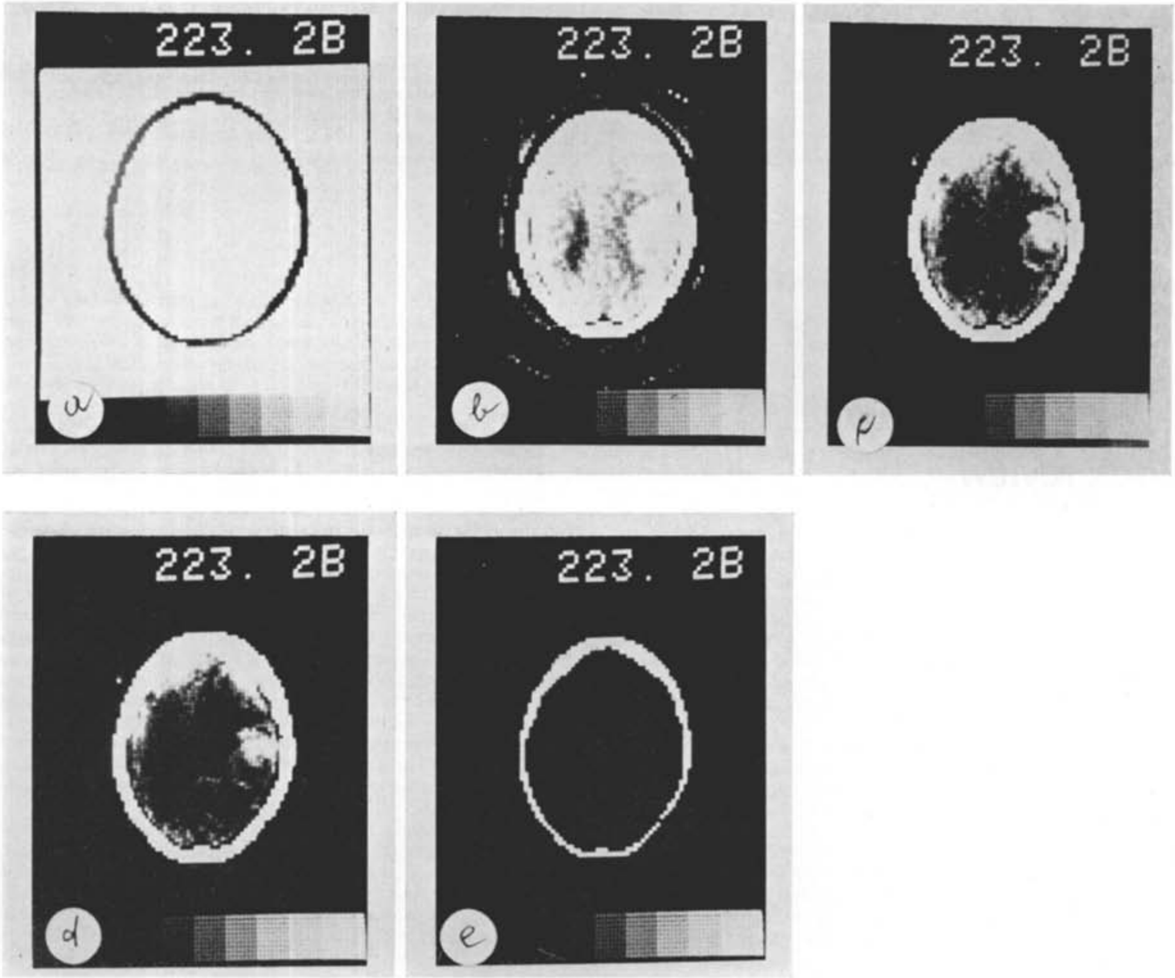

FIG. 10.
Illustration of "window level" adjustment.
(a) (Window level setting—100 units.) The black ring represents the patient's hair and the air trapped in it.
(b) (Setting 0) shows water in the ventricles.
(c) (Setting+15 units) shows tumour and haemorrhage.
(d) (Setting+20 units) shows details in the haemorrhage.
(e) (Setting+350 units) the white ring represents the bone of the skull.

tures side by side are taken at the same time during each scan of the patient.

DISCUSSION

It is evidently of interest to consider how far the sensitivity of this procedure exceeds that available with established techniques. The material presented in Fig. 9 gives some indication of the detectability of particular tissues; further analysis of the data presented suggests that the system may have a sensitivity two orders of magnitude greater than conventional methods in detecting soft tissue abnormalities.

It is possible that this technique may open up a new chapter in X-ray diagnosis. Previously, various tissues could only be distinguished from one another if they differed appreciably in density. In this procedure absolute values of the absorption coefficient of the tissues are obtained. The increased sensitivity of computerized X-ray section scanning thus enables tissues of similar density to be separated and a picture of the soft tissue structure within the cranium to be built up.

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Book review

Radiation Protection. By J. Shapiro, pp. xx+339, illus., 1972 (Cambridge, Mass., Harvard University Press, and London, Oxford University Press), £7·50 (hardback); £3·50 (paper covers).

This manual on radiation protection has two conflicting objectives. The author claims in the preface that "This manual was written for individuals who wish to become qualified in radiation protection as an adjunct to working with sources of ionizing radiation or using radionuclides in the field of medicine. It provides the radiation user with information needed to protect himself and others and to understand and comply with governmental and institutional regulations regarding the use of radionuclides and radiation machines." The guide to the use of the manual, however, informs the reader that "This manual was written for the training programme in the safe use of radionuclides in research conducted by the Harvard University Health Services." If this second objective had been implied in the title rather than the first, the manual would be a far more useful publication, especially as certain sections now dealt with inadequately would then have been irrelevant and presumably deleted. To meet the first objectives a more rigorous and extensive treatment is necessary on the use of "radiation machines", particularly in view of the contribution diagnostic radiography makes to population exposure; the section on "X-rays" takes up only twenty-nine pages!

The manual is divided into six parts.

Part I—Historical Prologue.

Part II—Principles of Radiation Protection. Referred to as a primer on the principles of radiation protection, contributes approximately a third to the volume of the book. Even at this stage, in its tables and illustrations, the presentation is very much biased towards the use of radionuclides at the expense of "radiation machines".

Part III—Radiation Dose Calculations. This deals exclusively with calculations on topics dealing with radionuclides and provides some very useful data and formulae for the radionuclide worker. The author elaborates with detailed dose calculations on ^{3}H, ^{131}I, ^{133}Xe and ^{32}P, chosen for their universal use in nuclear medicine.

Part IV—Radiation Measurements. The "various kinds of radiation detectors, the types of signals they produce and means of analysing these signals, with particular attention to Geiger-Müller counters and scintillation detectors as examples of the constant output and proportional output detectors respectively" are discussed. Included is a short but completely inadequate section on personnel and environmental monitoring. The presentation of radiation measurements from radionuclides and their interpretation are dealt with after an introduction to the statistical methods required for this.

Part V—Practical Aspects of the Use of Radionuclides contains little practical information for the radionuclide user in the United Kingdom. Reference is only made to the various regulations pertaining to radiation control in the U.S.A. Also included are practical safety precautions required when handling radionuclides. This is information which is readily available to the U.K. user in the Codes of Practice for the protection of persons against ionizing radiations.

Part VI—Ionizing Radiation and Public Health provides extensive and up-to-date data on the potential hazards involved in the large scale use of ionizing radiations. The merit of such a detailed account in a manual of this kind is questionable. A condensed version would not have detracted from its usefulness in keeping radiation hazards in perspective.

The manual ends with two appendices, the first on the use of powers of ten in dose calculations, the second contains a set of 25 problems for the reader to tackle, all dealing with radionuclides. A selected bibliography is appended for easy reference to a more rigorous treatment of the text, together with further useful references and an index.

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