Nuclear Medicine

An Introductory Text

Nuclear Medicine: An Introductory Text

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 Contents

It is always a great pleasure and honour to be asked to write a foreword for a new textbook.

The explosive expansion of diagnostic techniques, particularly in the imaging field, makes it nowadays impossible for those involved in the clinical practice and application of the various investigations to keep abreast with the new developments, let alone with the enormous world literature.

Nuclear medicine is now a well-established specialty straddling a wide field of medicine. Many of the techniques are firmly established and in constant use, but there is still a very significant gap in common knowledge between the day-to-day practice and the new developments in technology and the introduction of new radiopharmaceuticals. An up-to-date account of the state of the art therefore is most valuable and helpful for those interested in this specialty. Physicians, radiologists, and physicists are the ones mainly involved in the day-to-day work in this field, and their input has an impact on varying levels of the specialty.

Professor Williams and Dr. Ell present an overview of the current application of nuclear medicine to clinical practice. They assess the limitations of the various studies and above all put nuclear medicine into perspective in the practice of modern clinical medicine. Before one can consider the actual clinical application of nuclear medicine it is essential to appreciate the basic principles of the underlying physics and its technology. Similarly the practitioner must be familiar with an understanding of radiopharmaceuticals, a rapidly expanding field, and, last but not least, the radiation hazards associated with isotope studies.

Since this is a very practical book for the working physician and radiologist the authors have not attempted to cover the field in its entirety but rely on a more pragmatic approach to introduce the specialty to those who are eager to learn the basic principles.

It is now well accepted that modern imaging techniques cover a very wide spectrum from standard radiological investigations to the more complex studies, ultrasound, and nuclear medicine—all techniques which are very often complementary. For this reason definitive diagnostic pathways will have to be developed to identify the primary investigations in certain clinical settings and thus avoid unnecessary investigations or expensive duplications of studies. A full understanding of the broad spectrum of these techniques is essential before they can be used sensibly and rationally. This book covers one aspect very fully by providing an overview of the present position of nuclear medicine in its clinical setting.

Professor R. E. Steiner,
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Prefac

The existence of large textbooks on nuclear medicine and its specific aspects calls for an explanation of the aims of this small volume. As the title implies, this is an introductory text. It is intended for those many clinicians who need to use nuclear medicine facilities but who do not have time to keep in touch with the voluminous literature on the subject.

It is also intended for radiologists who must include in their training some knowledge of radioactive tracers, but who do not need to master its more specialized medical uses. For this reason topics such as the measurement of physiological spaces and metabolic studies are omitted and certain absorption tests are referred to only briefly. Similarly the very important role of radioactive tracers in haematology is dealt with in a single chapter. Radioimmunoassay, although often classed as part of nuclear medicine, is closely allied to clinical chemistry and has also been allocated only one chapter.

Many medical physicists are closely involved with providing a nuclear medicine service, and it is hoped that this clinically biased outline will be of interest to them. It should give them a bird's-eye view of the scope of the medical applications and current limitations of this branch of their work. Pharmacists concerned with producing radiopharmaceuticals should also gain insight into the clinical applications of their products. Radiographers, nucleographers, and technical staff required to operate nuclear medicine equipment should find this a useful text as it will give them a general view of the clinical problems their work will help to solve.

The authors have chosen to omit an introduction to the scientific basis of nuclear medicine, and readers seeking such information should refer to one of the current texts on the subject. Specific textual references seemed inappropriate in an introductory book. Instead a very short bibliography which will direct the reader to current literature in his field of interest is appended to each chapter.

P. J. Ell
E. S. Williams

Contents

1. Instrumentation

Specialized radiation detectors are used in nuclear medicine in order to: (1) detect emitted radiation; (2) measure emitted radiation, (3) obtain a visual display of the in vivo distribution of a radiopharmaceutical; and (4) obtain graphs and/or images of time-dependent data

Basic Mechanisms Involved

A radiation detector of the type utilized in nuclear medicine basically acts as a transducer which transforms incoming radiation (within the context of this book, gamma photons) into visible light (light photons). This is the property which made these radiation detectors known—scintillation detectors.

Scintillation detectors (crystals) can be obtained from a variety of materials, but the most commonly in use in nuclear medicine is sodium iodide, containing a carefully controlled quantity of Thallium impurity for stabilization of the scintillation property, NaI(Tl). A photomultiplier tube (PM tube), when coupled to the scintillation detector via its cathode, ensures that the emission of light photons from the crystal leads to the production of electrons in the photomultiplier tube. These are multiplied by it to such an extent that a measurable electrical pulse is generated at the anode of the PM tube

There is an important proportionality between the gamma radiation emitted from the patient or tissue, the scintillation generated in the crystal, and the electrical pulse generated in the photomultiplier tube. This allows for the objective analysis of the emitted radiation. Via amplifiers, the electrical pulse generated at the anode of the PM tube is fed into an electronic gating system which allows for the identification of the pulse in terms of its shape and intensity (pulse height analysis). Finally, the incoming electrical pulses are fed into electronic averaging and counting systems. Scalers enable fast count rates to be accurately recorded while rate meters display an average count rate, the time to which the average applies depending upon the instrument and upon its setting by the user (Figure 1-1).

The radiation detectors (crystals) can be made into different shapes and sizes. In nuclear medicine departments, one commonly encounters a variety of these designed to fulfill specific tasks.

Well Counters

In this apparatus (Figure 1-2), the radiation detector (crystal) is shaped into a well which can accept radioactive biological samples for counting purposes This type of instrumentation is often used for studies such as red cell or

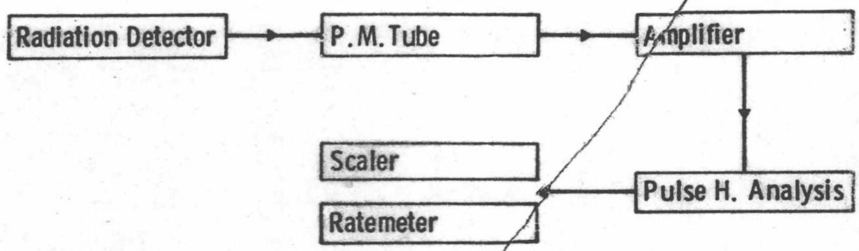

Figure 1-1. Standard configuration of a radiation detector and counting system.

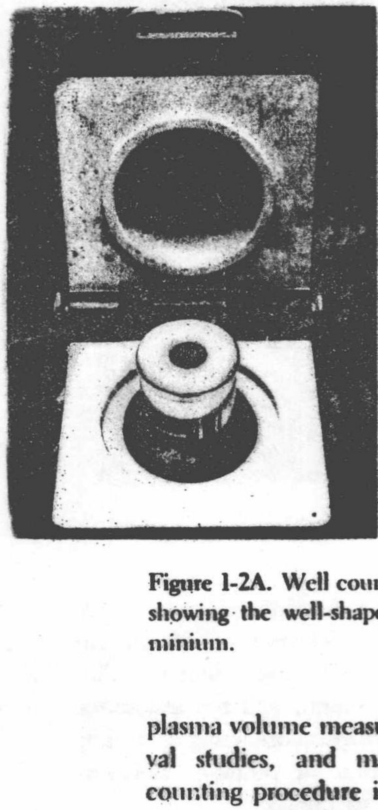

Figure 1-2A. Well counter with open shield (lead) showing the well-shaped crystal encased in aluminium.

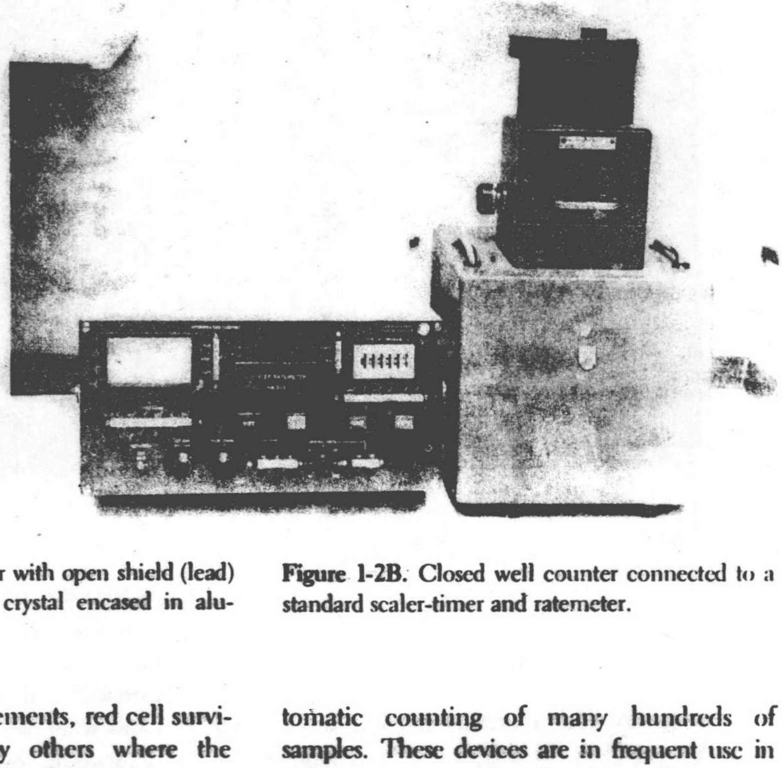

Figure 1-2B. Closed well counter connected to a standard scaler-timer and ratemeter.

plasma volume measurements, red cell survival studies, and many others where the counting procedure is usually rapid and not very many samples need to be recorded.

The well counter principle is maintained in the automatic counters which incorporate a sample-changer (Figure 1-3). Here a well counter design is usually fitted around a conveyor belt system which allows for the automatic counting of many hundreds of samples. These devices are in frequent use in radioimmunoassays and other tracer techniques. When more than one pulse height analyzer system is built into the electronics, double or even treble pulse height analysis and isotope counting are possible. The size and shape of the well counter can vary considerably, allowing for larger volumes to be

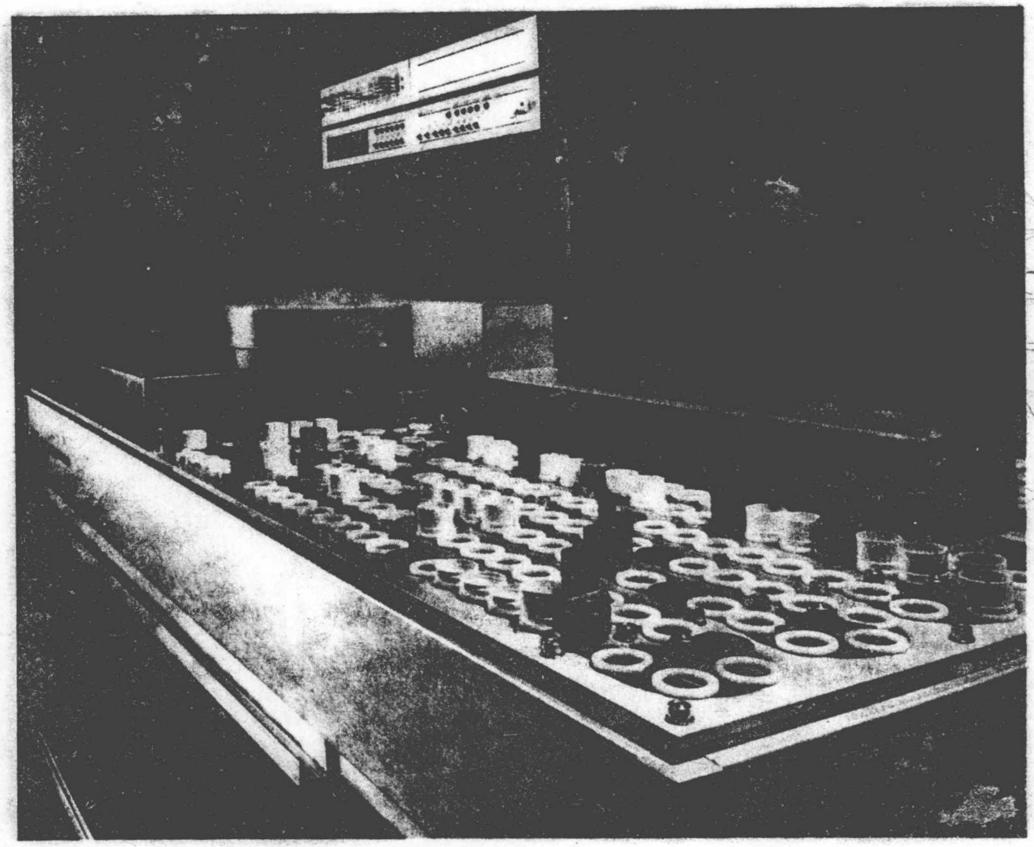

Figure 1-3. General purpose gamma counter designed to count many samples of a standard size and volume automatically.

counted. It is therefore possible to optimize the design of this type of instrumentation in order to measure radioactive urine samples, faeces, etc. (Figure 1-4).

Ionization chambers (a different type of radiation detector where the detector crystal is substituted by an inert gas) are more often used for the calibration of radiopharmaceuticals administered to patients (Figure 1-5). Automatic read and print-out systems are available, automatic selection of different energy windows for counting different radionuclides can be chosen, and the automatic calibration of syringes containing a variety of specific activities of different radionuclides is therefore facilitated.

Probes

A probe usually consists of a single 2- or 3-inch thick crystal coupled to a single photomultiplier tube and the conventional elec-

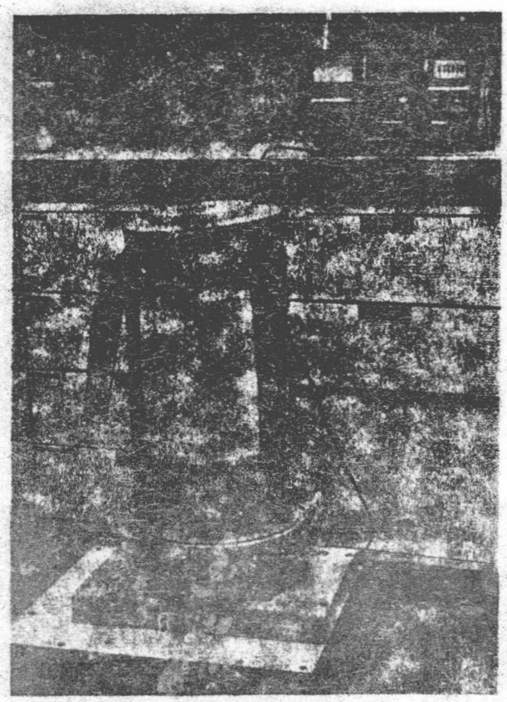

Figure 1-4. Gamma counter utilized in the measurement of single samples of larger volumes (urine, feces).

tronics. The crystal is, however, shielded (with lead, brass, aluminium, etc.) in such a way that a certain directional effect is achieved (Figure 1-6A). This shield or collimator implies that, within the limits chiefly given by the design of the collimator (single hole, multiple hole, parallel septa, tapered septa, etc.), the probe can detect and count over a particular depth of the body. Probes are also often referred to as external detectors. Single probes (as the apparatus shown in Figure 1-6B) can be made quite portable and are in extensive use (in the detection of deep vein thrombosis, cardiac function studies, and so on). Portable but multiple probe systems are available as trolleys and are ideal for bedside monitoring of indices of organ function (kidneys, lungs, brain) as in Figure 1-7.

Scanners

When a radiation detector (crystal) of 3 to 5 inches is linked to a mechanical arm, it is possible to modify the described systems to a point where the distribution of administered radiopharmaceuticals to patients is recorded to form a two-dimensional image. In the scanner the mechanical arm possesses a raster motion of the type diagramatically illustrated in Figure 1-8 and allows for the buildup of a final image. A display system is therefore required and is added to the basic electronics of such devices. In modern scanners a lesser or greater degree of data processing can be used with these instruments which allow for greater accuracy in data collection, analysis, and display (Figure 1-9). The scanner scans across the patient, recording line for line the activity distribution within the patient. The image obtained often gives a 1:1 ratio between object and image. This is ideal for the visualization of small areas or organs such as the thyroid. For the scanning of larger areas or organs, different degrees of minification can be utilized in the final display. Modern scanners can be modified to produce scans of the activity distribution within the whole body—whole body scans. Considerable progress has been achieved in this area. While a few years ago it could take as long as three hours to record such a whole body picture, multicrystal scanners or the equivalent gamma cameras working in whole body mode can record a

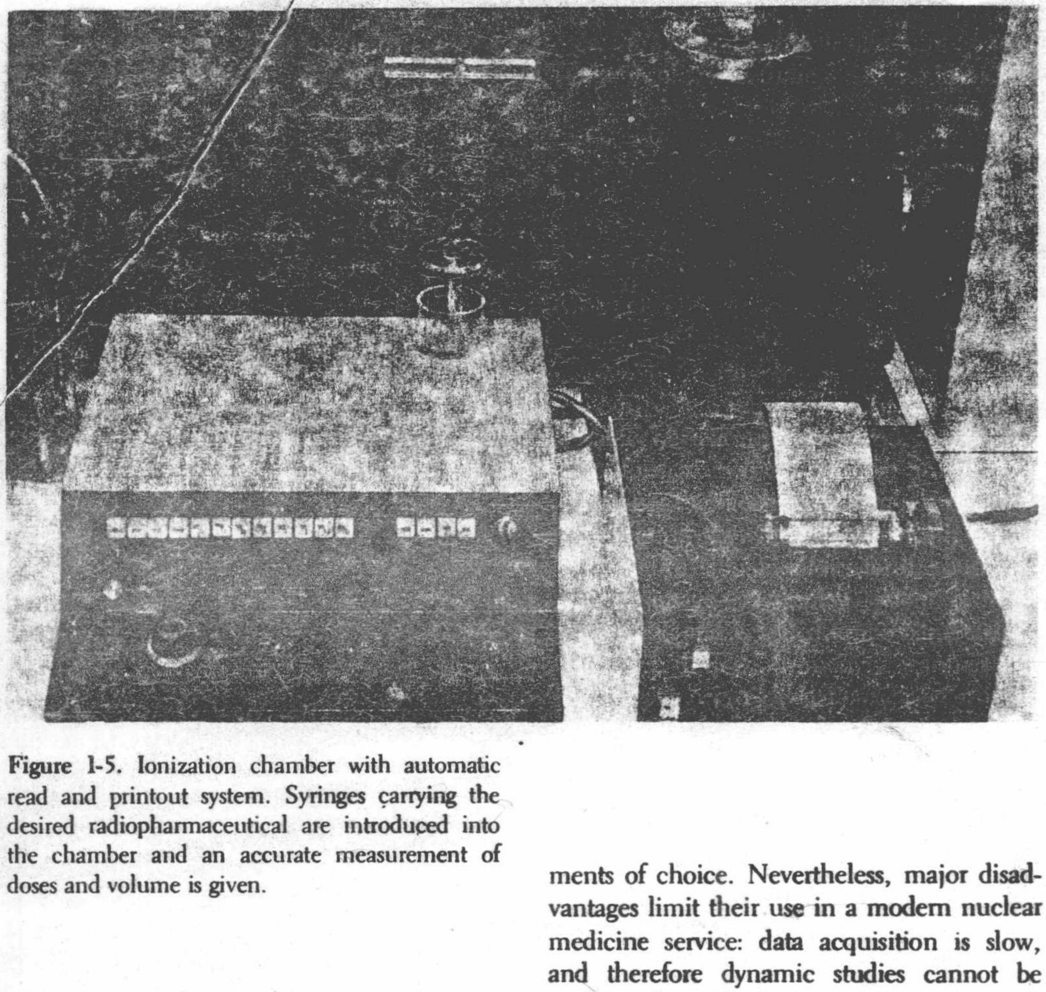

Figure 1-5. Ionization chamber with automatic read and printout system. Syringes carrying the desired radiopharmaceutical are introduced into the chamber and an accurate measurement of doses and volume is given.

whole body scan in 10 to 20 minutes (Figure 1-10). Scanners can be fitted with detectors above and below the imaging table where the patient lies. This allows for the simultaneous recording of anterior and posterior projections and both lateral projections. For the recording of isotope distributions from radionuclides of higher energy, scanners remain the instruments of choice. Nevertheless, major disadvantages limit their use in a modern nuclear medicine service: data acquisition is slow, and therefore dynamic studies cannot be performed; multiple projections of static studies are time-consuming and inaccurate; and data processing capability is limited.

Gamma Cameras

In the early 1960s, Anger developed the instrument which was to be known as the Anger gamma camera. This has become the most widely used imaging apparatus for radioac-

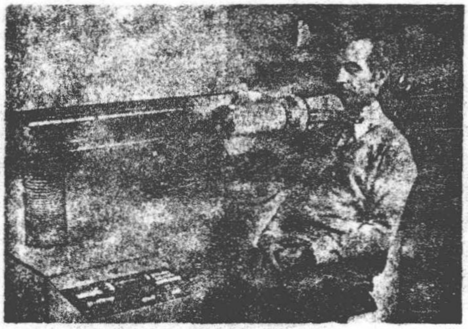

Figure 1-6A. Scintillation probe designed for thyroid uptake measurements.

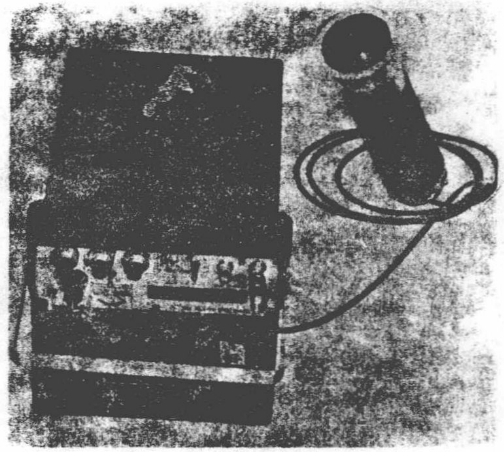

Figure 1-6B. Portable probe used for deep vein thrombosis detection.

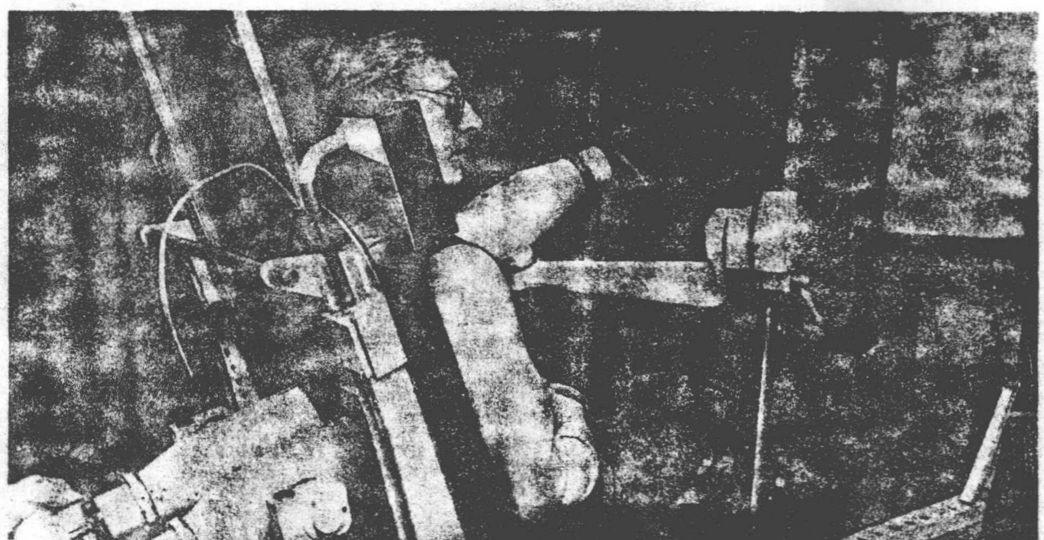

Figure 1-7. A multiple scintillation probe portable trolley system used for the investigation of individual kidney function.