Imaging for Medicine

Volume 1

NUCLEAR MEDICINE, ULTRASONICS, and THERMOGRAPHY

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Preface

The material in this volume was prepared and collected over the past four years with the growing realization that a technical revolution was in progress for diagnostic medicine. It became clear that for the wide variety of imaging instruments and methods finding their way into applications for research and clinical medicine, there was a scarcity of reference and text books for the scientist and engineer beginning in the field. Thus what began as a relatively small project for a single volume has grown into certainly two and probably three volumes to adequately cover the field. This first volume is expected to be followed within a few months by a second volume, dealing with diagnostic radiology, and within a year by a third volume, covering most other aspects of medicine that utilize spectra from the ultraviolet through the visible into the near-infrared.

The chapters in this book are divided into three groups. The first group deals with nuclear medicine and includes Chapters 1–8. These chapters are arranged to begin with a broad introduction to the subject (Chapter 1) followed by a sequence of four chapters (Chapters 2–5) that provide an in-depth review of the imaging instrumentation developed for the field. Chapter 6 deals with "evaluation" of imaging device performance, while Chapters 7 and 8 discuss two areas of considerable research activity.

The second group of chapters, Chapters 9 and 10, covers ultrasonic imaging. Chapter 9 provides a tutorial treatment of the physician's approach to ultrasonic examination, and Chapter 10 provides a theoretical analysis of the various aspects important in ultrasonic imaging. The third group of chapters, Chapters 11–13, spans the field of thermography. Chapter 11 again introduces the subject from the physician's point of view, Chapter 12 reviews instrumentation available as well as under development, and Chapter 13 presents a detailed theoretical treatment of the subject.

It is hoped that by mixing chapters covering the physician's diagnostic approach with the technical chapters, a more practical understanding of the strengths and weaknesses of the different modalities will be possible, and that it might even inspire new directions of research and development.

We are indebted to and thank Professor M. Paul Capp for his continuous encouragement and assistance, in addition to Ms. Beverly Bindes, Ms. Betty Porter, and Ms. Georgie May Quinn for their secretarial assistance.

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CHAPTER 1

Basic Information on Routine Diagnosis in Nuclear Medicine*

GÖTZ RASSOW

1.1. INTRODUCTION

The application of radionuclides in medicine has proved to be so fruitful that a separate scientific branch has developed: nuclear medicine.

Radionuclides are radioactive isotopes of the chemical elements and have the same chemical behavior as the stable (nonradioactive) isotopes. Radionuclides differ from them in their ability to undergo spontaneous nuclear disintegration. Nuclear medicine makes use of the effect of the radiation produced by the nuclear disintegration.

Nuclear medicine is divided into diagnostic and therapeutic procedures.

* *Note from editor.* This chapter was originally published as a booklet by Siemens Aktiengesellschaft, Berlin/Munich, 1970. We are indebted for their kind permission to use it as an introduction for our discussion on the "state of the art" in diagnosis with nuclear medicine. Although newer radiotracers are now used, the principles remain the same.

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1.1.1. Nuclear Therapy

Therapy makes use of the radiation effect of incorporated radionuclides for selective cell and tissue destruction.

1.1.2. Nuclear Diagnosis

Diagnosis makes use of the radiation effect of incorporated and non-incorporated radionuclides for information.

With the aid of radionuclides, medical research has made considerable advances, which have given rise to many routine methods of diagnosis. Since physics and engineering play a considerable role in this development, nuclear-medical diagnosis represents a complex scientific field. This chapter is intended to give the newcomer to nuclear medicine an insight into this field and to explain the physical and engineering terms required for an understanding of this subject.

1.2. NUCLEAR DIAGNOSIS

1.2.1. Indicator Method

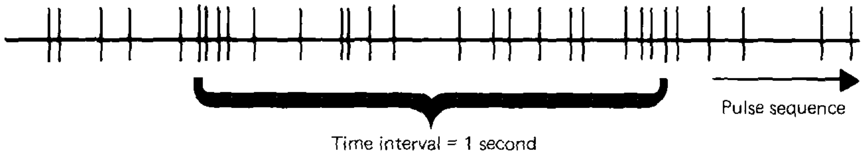
Nuclear-medical diagnosis is based on the indicator method. The indicator method with radionuclides has the characteristic that the information carried by them does not flow continuously as is the case of the indicator method with dyes. While individual color particles can be recognized as an indicator at any time through their color effect, radionuclides reveal their indicator effect only at the moment of nuclear disintegration.

On account of the spontaneity of nuclear disintegration, however, the disintegrations are statistically distributed with respect to time. Consequently, a large number of radionuclides have the effect of an indicator with continuously flowing information, when the information is conceived as disintegration rate, i.e., as the number of disintegrations per time interval.

Since nuclear disintegration manifests itself by the emission of radiation and the effect of the radiation is measured as an electric voltage pulse, the count rate is the measured quantity of the indicator method, i.e., as the number of pulses per time interval (Fig. 1-1). In practice, in most cases it is not necessary to distinguish between disintegration rate and count rate as absolute values are not measured. It is sufficient to know that under the measuring conditions used in nuclear medicine the count rate is proportional to the disintegration rate. The disintegration rate is referred to as activity A (cf. Section 1.4.2).

The simplest information that can be obtained from the indicator method consists of the comparison between various activities (finding the

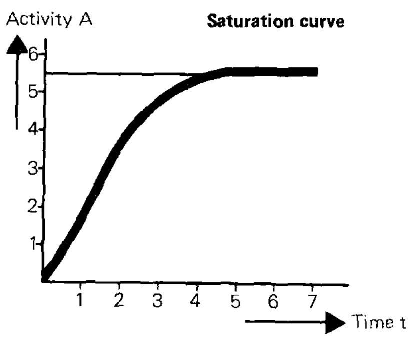
Count rate as number of pulses of a pulse sequence within a time interval



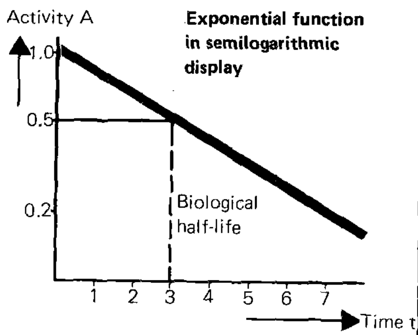
In this example the count rate is 20 counts per second.

Fig. 1-1

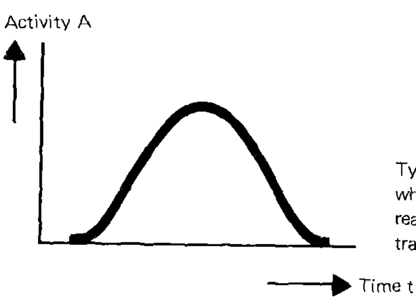
Graphic displays as example of basic technique 2



Typical curve obtained when a certain quantity of indicator finally ends up at the site of measurement.



Typical curve obtained when a certain quantity of indicator is transported from the measuring site at a speed proportional to the quantity still present.



Typical functional measuring curve, which indicates how fast the indicator reaches the site and how fast it is transported away.

Fig. 1-2

difference or quotient of the values A_1 and A_2). The indicator method would be fully exploited if information were given on the spatial and temporal change of the activity distribution in the organism. In this ideal case it would be necessary to know the dependence of the activity on the spatial coordinates x, y, and z as well as on the time t. This dependence is also called function f and it is written $A = f(x, y, z, t)$. Between the two extremes, the comparison of activity and the determination of the spatial and temporal distribution of activity, there is the information possibility of measuring the activity as a function of one or more of the variables x, y, z, or t, while neglecting the dependence of the remaining variables.

The analytical approach to the indicator method as described here forms a supporting frame into which the manifold nuclear-medical applications can be clearly arranged. The supporting frame is built up of five basic techniques of obtaining information now to be discussed.

1.2.2. Basic Techniques of the Indicator Method

Basic Technique 1

Comparison of activity. Comparison between two activities A_1 and A_2 is expressed as a difference or quotient, i.e.,

$$A = A_1 - A_2 \quad \text{or} \quad A = A_1/A_2$$

Basic Technique 2

Time-activity analysis (Fig. 1-2). The change of activity with respect to time at given site is given as

$$A = f(t)$$

Basic Technique 3

Profile Scintigraphy (Fig. 1-3). The spatial distribution of the activity measured as activity distribution along a path when a temporal change of activity can be neglected:

$$A = f(x)$$

Basic Technique 4

Scintigraphy (Fig. 1-4). The spatial distribution of the activity measured as activity distribution in a plane when a temporal change of activity can

Graphic display as example of basic technique 3

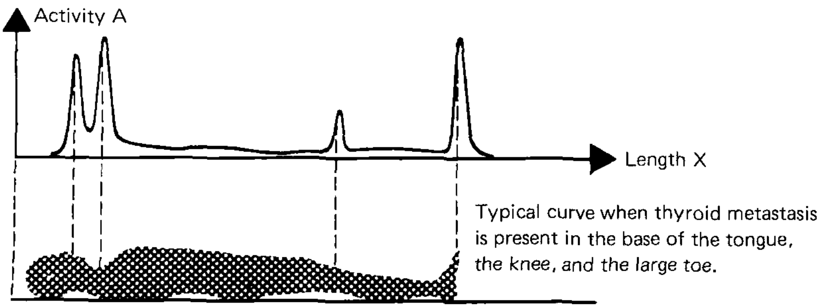


Fig. 1-3

be neglected:

$$A = f(x, y)$$

Photoscan (Fig. 1-5). If a photorecorder is used for displaying the data, the change in the activity appears as a variation in the film blackening. In this case graphical display in a plane is possible.

Color Dot Scan (Fig. 1-6). If a color dot printer is used for displaying the data, the change in the activity appears as colored regions. In this case graphic display in a plane is possible.

Basic Technique 5

Camera Scintigraphy. The spatial distribution of the activity measured as activity distribution in a plane at various times is given as

$$A = f(x, y, t)$$

Serial Scintigraphy (Fig. 1-7). The graphical representation of a quantity as the function of three variables is unclear. Since with scintigraphic camera exposures a change of activity results in a step between light and dark, graphic representation in space is possible.

With serial scintigraphy the principle of cinematography is realized in scintigraphy. In this representation the information obtained reproduces very clearly the spatial changes of activity within the camera field of vision if the pictures "shot" at various times are compared with each other.

Function Scintigraphy (Fig. 1-8). Another representation of the information obtained with camera pictures is possible with special technical means, which only allow small regions of the field of vision of the camera, i.e., picture elements, to be evaluated. The evaluation of the change of activity