REVIEW

External-Beam Methods in Biomedical Work

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ABSTRACT

The useability of external-beam proton-induced X-ray (PIXE) and gamma-ray (PIGE) emission, backscattering spectrometry (BS), and the particle-particle method in biomedical work is demonstrated. Detection limit values obtainable by the methods for typical biomedical samples under practical conditions are given and compared. Advantages, drawbacks, and restrictions of the methods are discussed. Examples of the applications of the methods in biomedical work are given.

Index Entries: External-beam methods, in biomedical work; PIXE; PIGE; nuclear analytical techniques; external beam particle-particle method.

INTRODUCTION

The great range of potential applications and advantages of using charged particles produced by a particle accelerator for elemental analysis have been amply demonstrated (1). Bringing the charged-particle beam into the atmosphere through a thin exit foil offers still more applications in biomedical work.

An advantage of the external beam is that especially volatile materials, like many biomedical samples, may be analyzed. Furthermore, the...
heat dissipation from the surface of the sample in air (or, alternatively, other gases) is effective, and, if required, it is easy to increase sample and exit-foil cooling. By using an external beam, the number of steps in the sample preparation are reduced, which thus reduces the risk of sample contamination. The experimental setups are also usually simple.

The present work introduces the external-beam methods of Particle-Induced X-ray Emission (PIXE), Particle-Induced Gamma-ray Emission (PIGE), Backscattering Spectrometry (BS), and the particle–particle method and gives some examples of the applications and usefulness of the methods in biomedical work.

**EXTERNAL-BEAM PIXE**

The PIXE is well suited for the analysis of elements heavier than aluminum (Al). It is perhaps the most widely used analysis method based on charged particles. Because external-beam PIXE has been thoroughly surveyed by Williams (2), only some examples of biomedical applications and general remarks are given here.

External-beam PIXE has been used frequently in our laboratory for the analysis of biomedical samples, such as blood serum, blood plasma, cerebrospinal fluid, bone, and teeth (3-6). Of special interest is the ability to detect selenium (Se) in body fluids. A PIXE spectrum of an erythrocyte sample obtained by 2.4 MeV protons is presented in Fig. 1. A rather thick pinhole absorber (7) (hole diameter 0.1 mm) of 150 μm thick Al was used in the measurements because of the large iron (Fe) content of the sample. The sample Se content is about 0.2 ppm by dry weight. The Se detection limit is about 0.1 ppm by dry weight, in this case (in a 25-min run). A PIXE spectrum of a human-blood-serum sample obtained by 3.2 MeV protons is presented in Fig. 2. A 630-μm thick Kapton absorber was used in front of the detector to reduce the proportion of low-energy X-rays. The sample Se content is 0.009 ppm by dry weight. The detection limit of Se is about 0.007 ppm by dry weight and about 0.0006 ppm by wet weight, in this case (in a 20-min run).

Minimal sample preparation is needed since only the drying of the samples is necessary. When drying, care should be taken of the temperature during the process, since volatile elements like bromine are lost easily (4). The absolute concentration values were determined by adding known amounts of the elements as internal standards. Yttrium has been added to the samples as an internal monitor (~14 ppm). A detailed description of the sample preparation method is given in ref. (3).

The optimum-proton-energy region for the analysis of biomedical samples is 2.5-3.5 MeV, depending to some extent on the element to be detected (7). In this $E_p$ region, the measuring times needed to achieve the best limit of detection obtainable under practical conditions are the shortest. At energies of above 3.5 MeV, the situation worsens rapidly.