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TITLE ANALYSIS OF BIOLOGICAL SAMPLES USING PROMPT GAMMA RADIATIONS INDUCED BY 14.7-MeV NEUTRONS

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ANALYSIS OF BIOLOGICAL SAMPLES USING PROMPT
GAMMA RADIATIONS INDUCED BY 14.7-MEV NEUTRONS

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(Analysis Using Prompt Gamma Radiations)

ABSTRACT

We investigate a method for determining the elemental composition of biological samples that uses prompt gamma rays induced by 14.7-MeV neutrons. Alpha particles are produced simultaneously with the neutrons, which exit opposite the alpha detector through the vacuum chamber wall. The sample under investigation is irradiated and emits gamma radiations in a spectral energy distribution characteristic of the material. Barium-fluoride (BaF_2) and high-purity germanium (HPGe) gamma detectors view the sample and record the spectrum of gamma radiation.

Index Entries: associated-particle technique; prompt gamma radiation; time-coincidence measurement; barium fluoride; high-purity germanium; coincidence measurement; two-dimensional matrices; fluorine; multi-element analysis.

Introduction

At the present time there are a number of nuclear analytical techniques available for material analysis that are often complementary in the information they provide. We have been investigating another method, the associated-particle technique, that may add to the arsenal already available. Based on the d-t reaction, it is used to produce 14.7-MeV neutrons and (approximately) 3.5-MeV alpha particles.

Figure 1 illustrates a schematic of the technique. A deuteron beam with 100- to 150-keV incident energy strikes a tritiated titanium target, producing neutrons and alpha particles that are emitted 180 deg from each other. An alpha-particle detector detects alpha particles from the reaction and defines

a cone of correlated neutrons that can be used to analyze the material. The neutrons interact inelastically with the material under investigation and produce excited nuclei that decay, emitting prompt gamma radiation. This radiation, which is characteristic of the material that was excited by the neutrons, can then be used to identify the material.

Method

The technique consists of performing a time-coincidence measurement between the detected alpha particle and the gamma ray resulting from the neutron inelastic reaction. The coincidence requirement results in a substantial reduction in the background events present in the spectrum and allows real-time analysis to be performed.

The alpha-particle detector, consisting of 50 μm of a fast plastic scintillator (BC-400) deposited on an acrylic disk, detects alpha particles at a distance of 10 cm from the production target. The detector's thickness was chosen because it has ~100% efficiency for detecting alpha particles produced in the reaction and very little efficiency for detecting neutrons, x rays or gamma rays. The diameter of the detector is 1.9 cm; this can be modified with collimators. A thin nickel foil (0.00013 cm thick), located on the front surface of the detector, eliminates low-energy deuterons that are elastically scattered from the tritium target.

A number of gamma-ray detectors have been used, including barium fluoride (BaF_2) and high-purity germanium (HPGe). The BaF_2 provides moderate energy resolution (with an efficiency comparable to that of a sodium iodide) and the best time resolution for the coincidence measurement, resulting in the best volume localization for the material under investigation. The HPGe provides very good energy resolution with moderate time resolution. However, for material analysis, the latter is the best candidate because it allows

for the interpretation of complex spectra that often result from composite materials.

The data acquisition system comprises NIM and CAMAC electronics interfaced to a VMEbus computer. This enables us to acquire and store data in two-dimensional matrices of time vs energy and to project, in real time, the energy spectra associated with the object under investigation. Spectra for background gamma radiation sources are also available from the same measurement, allowing for immediate elimination of gamma rays not associated with the material under investigation. Our present system is an adaptation of the VALET Plus system that was developed and supported by the European nuclear laboratory, CERN. Data from the measurements may be stored on streamer tape or on the hard disk of the peripheral computer used to communicate with the VMEbus processor.

Results

To demonstrate the technique, we performed qualitative measurements on a limited set of targets. Figures 2-7 show examples of spectra obtained with BaF_2 and HPGe detectors. All of these figures correspond to energy projections associated with the true-time-coincidence window. Figures 2 and 3 are spectra obtained with the BaF_2 and HPGe detectors for nitrogen. The most prominent peak in this spectrum is at 5.105 MeV. The single-escape peak is also present along with the 4.439-MeV full-energy peak from carbon. Carbon is produced via the (n,n'd) reaction on the nitrogen target. Another photopeak at 2.313 MeV is also a signature for nitrogen. Figures 4 and 5 are the spectra for oxygen. The major features in the HPGe spectrum are the 6.13-MeV peak, the single-escape 5.619-MeV peak, and the double-escape 5.108-MeV peak. When both elements are present in a sample, the double-escape peak from oxygen interferes with the 5.105-MeV full-energy peak from nitrogen

The peaks discussed in Figs. 2-5 are the fingerprints that are used to identify nitrogen and oxygen. Carbon also has a simple spectrum with a full-energy peak at 4.439 MeV and a single-escape peak at 3.928 MeV.

Figures 6 and 7 show examples of spectra from a composite material containing carbon, nitrogen, hydrogen, and oxygen for the BaF_2 and HPGe detectors, respectively. Clearly, the primary signature gamma-ray peaks are present for all of the major constituents of the material. Also present in the HPGe spectrum is a gamma-ray peak for lead, which is used as part of the gamma-ray shield surrounding the detector.

One element that is difficult to observe with standard activation techniques, especially in the presence of oxygen, is fluorine. To demonstrate that the associated particle technique encounters no problems in distinguishing fluorine from oxygen, we have made a measurement using a fluorine target. Figure 8 shows the fluorine spectrum measured with the HPGe detector; the most prominent gamma ray is at 1.98 MeV. This corresponds to the decay of the first excited state in ^{18}O , which is formed via the (n,d) reaction on fluorine. There are also at least three gamma rays present that result from the de-excitation of levels in ^{18}F . A comparison of Figs. 5 and 8 shows that the spectra for oxygen and fluorine are quite distinct.

Summary

We have demonstrated that the associated-particle technique has excellent potential for qualitative and, probably, for quantitative analysis of materials. The technique has several strong points, including the ability to observe essentially all elements, except hydrogen and helium, and to analyze many elements in a single measurement. Furthermore, this multi-element analysis can be done in real time, so that the analysis is finished when irradiation is completed.

FIGURE CAPTIONS

Fig. 1. Schematic of the associated-particle technique.

Fig. 2. BaF_2 spectrum for nitrogen.

Fig. 3. HPGe spectrum for nitrogen.

Fig. 4. LaF_3 spectrum for oxygen.

Fig. 5. HPGe spectrum for oxygen.

Fig. 6. BaF_2 spectrum for composite material (C, N, H, and O).

Fig. 7. HPGe spectrum for composite material (C, N, H, and O).

Fig. 8. HPGe spectrum for fluorine.