THE INSTRUMENTAL DETERMINATION OF CADMIUM IN BIOLOGICAL SAMPLES AT NANOGRAM LEVELS WITH THE AID OF A COMPTON SUPPRESSION SYSTEM AND EPITHERMAL NEUTRON ACTIVATION ANALYSIS

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Instrumental epithermal neutron activation analysis in conjunction with Compton suppression methods has been used to determine cadmium concentrations in seven biological reference materials. The $^{114}\text{Cd}(n,\gamma)^{115}\text{Cd} (t_{1/2} = 53.3 \text{ h}) \rightarrow ^{115}\text{In} (t_{1/2} = 4.5 \text{ h})$ reaction using the 336.3 keV photopeak was successfully employed to achieve an overall precision between 4%-15% and detection limits between 10-20 ng/g. The accuracy of the results as compared to the certified or compilation values was in excellent agreement.

INTRODUCTION

As a result of concern over pollution, the general public has become aware of the dangers of elevated concentrations of certain trace elements in the environment. Along with lead and mercury, cadmium potentially a very toxic element, still remains as one of the most investigated heavy metals in the environment and needs to determined at the nanogram level with high precision. The most common sources of cadmium are in food and tobacco. The amount of cadmium in food may be as high 0.1 µg/g, while in tobacco as high as 0.45 µg/g per cigarette. In industrial operations such as refining and smelting, cadmium readily occurs in concentrations that are potentially hazardous. Although the sources of cadmium are easily noted, the effect of cadmium in biological systems is very complicated. Cadmium is a cumulative toxin and increases in concentrations in tissue as exposure time increases. Concentrations of cadmium in the kidney, the main organ target, peak around age fifty. The concentration levels of other organs may peak at earlier ages. The lungs and the gastrointestinal tract are also areas of the body which contain high levels of cadmium. The rest of the body has relatively lower concentrations of cadmium distributed throughout it.
Almost all previous neutron activation analysis (NAA) methods used to determine very low levels of cadmium in biological materials have required pre-chemical or post radiochemical separations. These methods are necessary as a result of the presence of sodium and bromine (often prevalent in biological samples) which become easily activated and give rise to the dominant photopeaks of $^{24}$Na and $^{82}$Br and the associated high background continuum due to Compton scattering. Separation techniques are labor intensive, often including procedures of digesting the material, and needing careful evaluation of separation of interferences and efficiency measurements. Ideally, a non-destructive nuclear method would eliminate the above inherent problems without the need for chemical separations. During the last several years our laboratory has been investigating the use of epithermal NAA in conjunction with a Compton suppression system to lower the detection limits of crucially important trace elements in biological samples. Epithermal NAA has been successfully employed in a wide variety of geological samples but little published work has appeared for the determination of trace elements in biological samples with the exception of aluminum. Compton suppression techniques have been used in many types of nuclear physics, prompt-gamma neutron activation analysis and low level radioactivity investigations. Few papers have appeared on its use in neutron activation analysis and almost no data have appeared on the use of certified reference materials in conjunction with Compton suppression. In this paper we report on the use of a Compton suppression system to determine nanogram quantities of cadmium in biological matrices without the use of any pre- or post chemistry separations.

EXPERIMENTAL

Compton Suppression Spectrometer

In Compton scattering the gamma-ray transfers only a portion of its total energy when it initially interacts in the sensitive volume of the germanium crystal. The scattered gamma-ray may be either absorbed in a subsequent interaction or it may escape the detector. If the scattered gamma-ray escapes the detector then only a fraction of its energy will show in the energy spectrum resulting in the Compton continuum. In order to suppress this continuum the Compton suppression system employs an active shield; in this case NaI(Tl), which completely encloses the germanium detector. The active shield is electronically coupled to the germanium counting system by an anti-coincidence circuit. If a gamma-ray is Compton scattered, out of the germanium detector and subsequently detected by the active NaI(Tl) shield, then that event is disabled. If, however only the germanium detector detects an event then the signal is enabled. There are three dominant modes of gamma-ray interactions with matter: photoelectric effect (<150 keV), Compton scattering (150 keV - 4 MeV) and pair production (>1,022 MeV). In the region between 150 keV and 4 MeV the most important interaction process of gamma radiation with germanium is Compton scattering. Thus, if one can reduce the Compton continuum arising from gamma-rays of energies which dominate the spectrum (e.g. sodium and bromine isotopes) then in theory it would be possible to detect elements which have characteristic photons usually lost in the background. Compton suppression is best suited for gamma-rays which are not in coincidence with other gamma-rays or else have a high proportion of the photons emitted in one dominant gamma-ray. For instance, the sensitivity to detect the two coincident $^{60}$Co peaks of 1173 and 1332 keV would