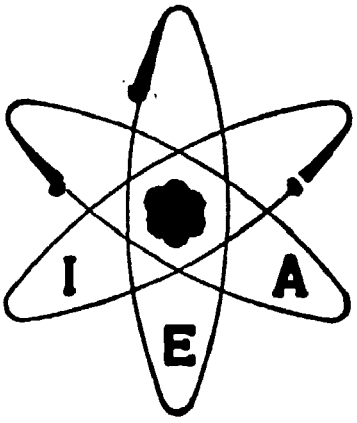

THE USE OF RESONANCE SCATTERING OF CAPTURE GAMMA RAYS AS AN ANALYTICAL TOOL

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PUBLICAÇÃO IEA N.º 383

Fevereiro — 1975

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ABSTRACT

With the practical application in mind, we have investigated the sensitivity for the resonance scattering of capture gamma rays as a tool to measure comparatively small concentrations of certain elements in bulk materials. Looking at the resonance for lead excited by iron capture gamma rays it is possible to measure concentrations down to less than 100 ppm. The advantages of the new technique are compared with other existing methods. The application of nuclear resonance scattering in prospecting for zirconium ores is emphasized.

Introduction

We have investigated the possibility of measuring non destructively, concentrations of some elements in bulk by means of the resonance scattering of capture gamma rays. Using this method of excitation has several advantages over the more conventional methods, such as neutron activation analysis, chemical separation, etc. For instance, by using capture gamma rays we do not activate the material and consequently we can use a large quantity of the sample without any radiation hazard. The excitation occurs in a stable isotope and therefore no active isotope is produced.

Experimental Arrangement

The resonant scattering of capture gamma rays is a quite well known phenomena[3,6] which is used mainly for the determination of nuclear parameters of excited levels and also of de-excited levels of a target nucleus.

Since the first work on resonance scattering of capture gamma rays made by Fleischman[6], a considerable amount of literature has appeared demonstrating that the resonance effect is not as rare as was thought[11].

The experimental arrangement for the resonance scattering of gamma rays used in this work has been previously described by Bianchini[5]. The gamma source is placed in the reactor core as is shown in figure 1 and provides at least one order of magnitude higher gamma fluxes on the position of the scatterer than is usually obtained with other existing arrangements[5].

In table 1 are given some pairs of gamma sources and resonant scatterers which could be used for the analysis of certain bulk materials. In order to make a comparison between these pairs in terms of their analytical capabilities we also give in table 1 the relative intensity normalized in such a way that the Fe-Pb combination is taken as 100.

The relative intensity is defined by the ratio:

$$R = \frac{\sigma_n \sigma_{\gamma\gamma} I_\gamma \rho_e f_e f_s \lambda (1 - e^{-\ln 2\, x_o/\lambda}) \times 100}{\sigma_n' \sigma_{\gamma\gamma}' I_\gamma' \rho_e' f_e' f_s' \lambda' (1 - e^{-\ln 2\, x_o'/\lambda'})}$$

where

σ_n is the thermal neutron cross section of the gamma source target (barn)

$\sigma_{\gamma\gamma}$ is the average resonance scattering cross section (barn)

I_γ is the gamma intensity of the source in photons by 100 captures

f_e percentage of the isotope responsible by the resonant gamma

f_s percentage of the isotope responsible by the resonant level in the scatterer

ρ_e density of the gamma source material

x_o scatterer thickness (cm)

λ mean free path of the resonant photon in the gamma source material (cm)

The primed parameters corresponds to the pair Fe-Pb. The product $\lambda(1-e^{-\ln 2 x_o/\lambda})$ is proportional to the maximum intensity of gamma rays available from the gamma source taking in to consideration self absorption. For the relative intensity calculation x_o was taken to be equal to 7.5 cm which is the space available for the gamma source material (width of a fuel element) in the IEAR 1 reactor.

In order to get an idea about the limitations of this method we have perfomed some measurements utilizing the resonant pair Fe-Pb. Irradiations were made using a constant volume of material in which the lead content dispersed was varied. The intensity of the 7279 keV line of iron elastically scattered by the lead was calculated and plotted against the amount of lead added to the material (figure 2). As can be seen the data form a straight line which passes through zero. The percentual error increases as we go to lower amounts of lead in the material due to the statistics. However, in figure 2 we can see that we are able to detect down to less than 100 mg of lead in bulk sample in the actual conditions. Considering that we can deal with sample masses of the order of 1 kg we can say that we are able to detect less than 100 ppm in bulk. This experiment was realized using a Ge(Li) detector of 42.5 cc separating the scatterer with a solid angle of 0.011 steradian.

This experiment was not optimized in order to get the minimum detectable amount of lead in bulk because the amount of gamma source material utilized was half the maximum permited by the physical space available. Even so, if use is made of a 3'' x 3'' NaI detector the counting efficiency could be increased by roughly a factor of 10. This means that the minimum trace quantity of lead in a bulk sample which can be detected is of the order of 5 ppm. The method however does not claim to be the most sensitive. But, in terms of lead there are very few non-destructive methods available which could compete favourably.

Knowing the dependence on various external parameters, etc , one should have a bette basis for choosing the best experimental conditions and also for understanding the factors limiting the method If use is made of NaI detectors and if better geometries are arrived at, better values can be achieved in terms of sensitivity

Conclusion

Although considerable number of resonant levels have been detected so far[11] only in a very few cases are the effective elastic cross sections known In spite of this, only the existence of a resonance with a particular nucleus is sufficient to permit the detection a given isotope in bulk. The quantitative calibration of the method can be easily carried out by adding known quantities of resonant nucleus to the bulk sample Thus, in some cases where no other method exists for the detection of an isotope it could prove possible to make use of this new technique

One possible aplication of this method is not only in prospecting new ore sources of some of the elements present in table 1, but rather as a tool to rapidly compare different samples of minerals already available Thus, for instance, one material of nuclear importance (table 1) is zirconium which having a low neutron cross section is difficult to analyse by conventional activation analysis methods or chemical separation processes Both are extremely time consuming when we consider that analysing a sample of 600 g of Zr ore (sand) takes no more than 30 minutes to obtain the Zr content taking into consideration the minimum amount of zircon ($ZrSiO_4$) normally available in the various ore deposits

We directed our attention to Zr because it is one of the elements with a lower sensitivity (table 1) and because zirconium has received special attention from the nuclear industry because of its resistance to corrosion and its low cross section for neutrons

Table 1

Scatterer	Gamma Source	E (MeV)	σ (mb)	Relative Intensity	Reference
$^{90}_{40}Zr$	Se	8 496	3050	3 3	5,6
$^{11?}_{50}Sn$	Cu	7 010	1150	2 5	7,8
$^{141}_{59}Pr$	Cl	6 115	110	193 0	12
$^{142}_{60}Nd$	Co	6 877	720	204 6	9
$^{202}_{80}Hg$	Co	4 922	5800	114 0	9
$^{205}_{81}Tl$	Fe	7 646	370	36 5	5,6
$^{208}_{82}Pb$	Fe	7 279	5620	100 0	10,11
$^{209}_{83}Bi$	Co	5 603	1050	136 9	9

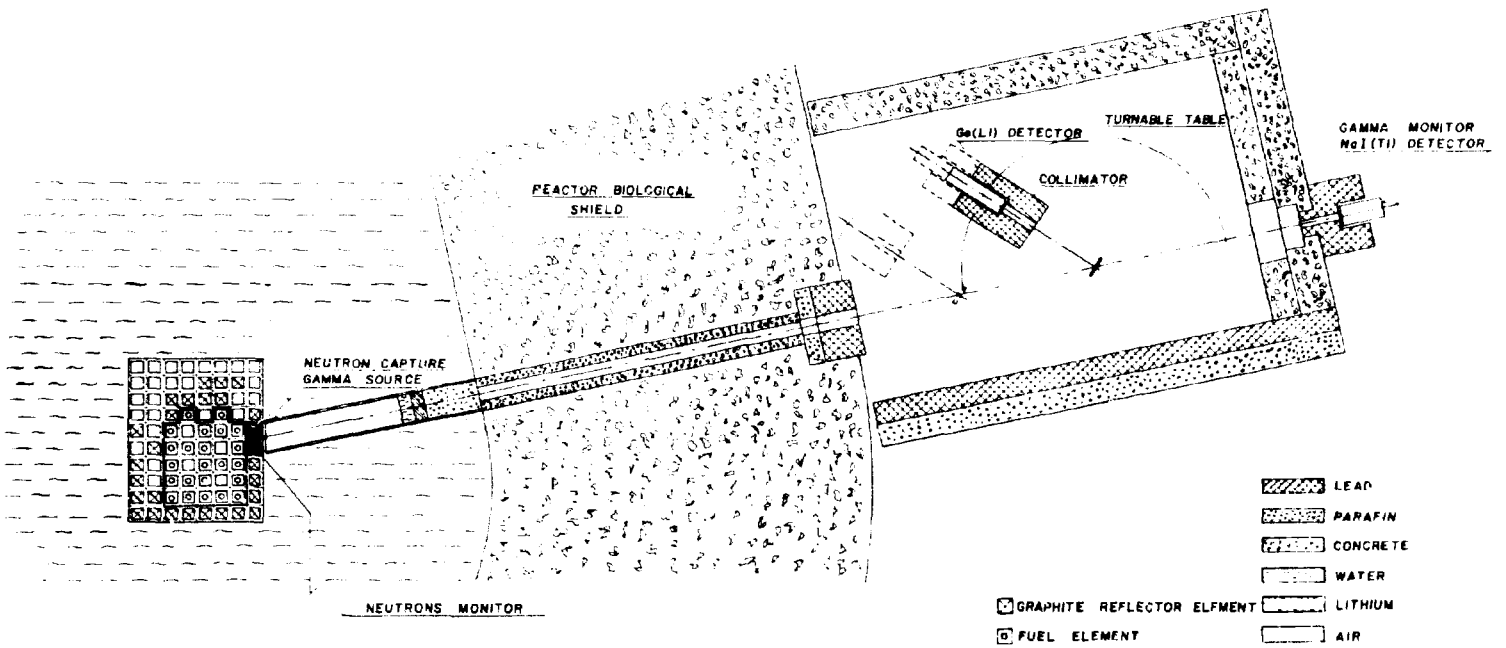

Figure 1

Experimental facility

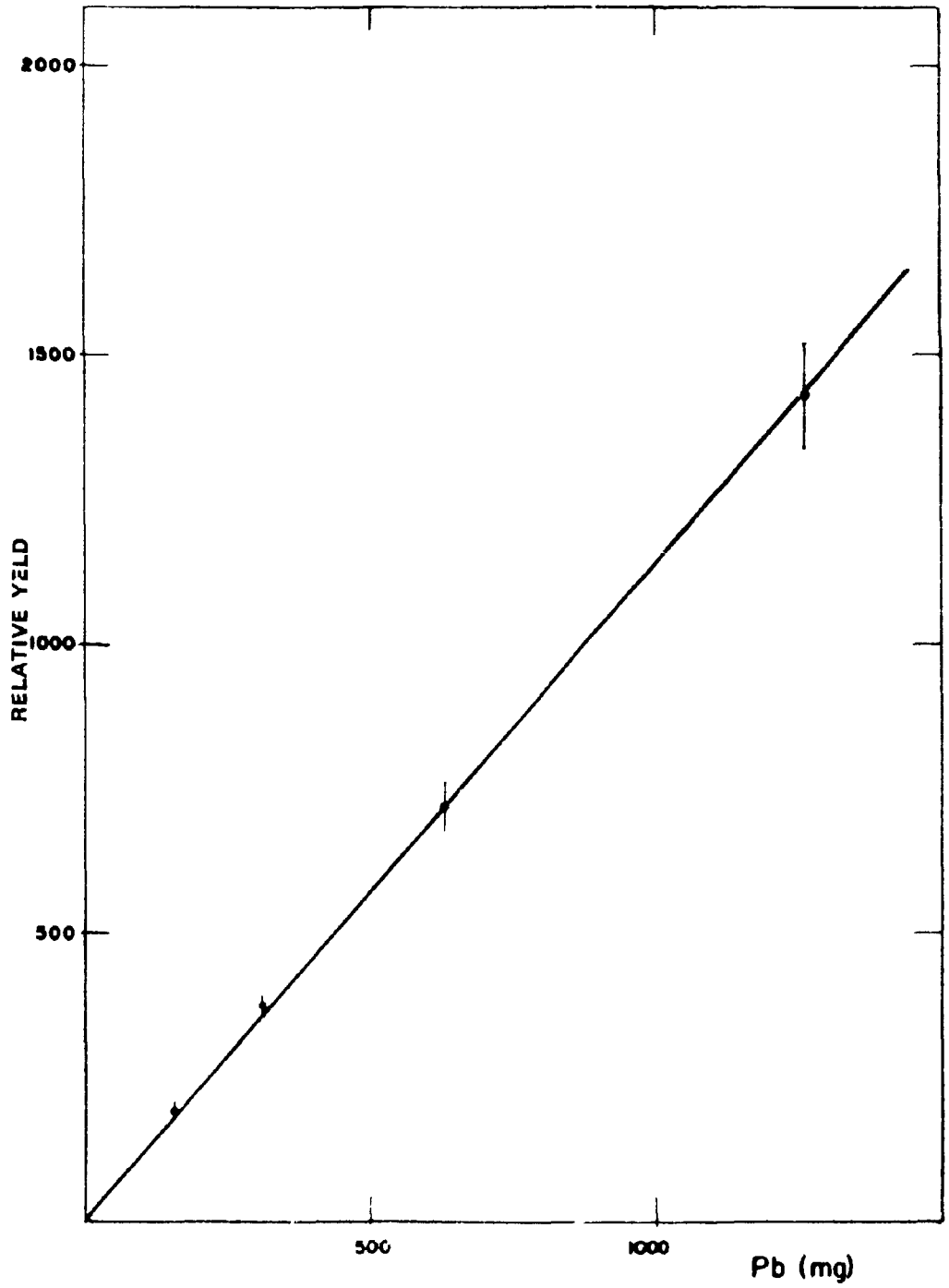

Figure 2
Concentration of lead in bulk measured by resonant scattering of gamma rays from iron

Acknowledgments

The authors gratefully acknowledge invaluable discussions with Dr. W.C. Parker, Dr. R.R. Franco and Dr. R. Fulfaro. They also wish to tank A. Ortega for aid in sample preparation.

RESUMO

Com aplicações práticas em mente, investigamos a sensibilidade da técnica de espalhamento ressonante de raios gamas de captura como um instrumento para medir pequenas concentrações de certos elementos na matéria. Investigando a ressonância do chumbo excitado por raios gamas de captura do ferro foi possível medir concentrações até menos do que 100 ppm. As vantagens da nova técnica são comparadas com outros métodos existentes. É ressaltada a aplicação de espalhamento ressonante nuclear em prospecção de minérios de zircônio.

RÉSUMÉ

En vue des applications pratiques, on a recherché la sensibilité de la résonance de dispersion des rayons gamma de capture comme une méthode pour mesurer concentrations comparativement petites de certains éléments en gros volumes.

En observant la résonance du plomb excité par des rayons gamma de capture du fer on peut mesurer concentrations au dessous de 100 ppm.

On compare la supériorité de cette nouvelle technique avec d'autres méthodes existants. On parle aussi de l'application de la résonance nucléaire de dispersion pour prospecter les minerais de zircon.

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