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Investigating the possibility of detecting iron and elements in the blood using the PIGE method with high-energy protons

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Abstract
PIGE (Particle Induced Gamma-ray Emission) is a nuclear technique for detecting the percentage of light elements by gamma-ray characteristic. Present research discusses the possibility of detecting iron and other elements in the blood by using PIGE method with 20-25 MeV proton beam.The proton source and the blood elements were defined in the input file of the MCNPX code. The characteristics of gamma-rays for each blood elements were calculated by *F8 Tally in a SiPM detector. The percentage of iron in blood is also formulated versus the detector response in the characteristic of gamma ray for iron. The results indicate that PIGE method with the 25 MeV energy of proton-induced is ideally suitable for detection iron and elements in blood.
Keywords: PIGE, blood, SiPM, iron, MCNPX, proton

Introduction
The PIGE technique is based on detection of the prompt gamma-rays originated from nuclear reactions during ion beam bombarding the nuclei of the target. Typically protons with energies in the (1–3 MeV) energy range for ion beam analysis, PIGE is more applicable for light elements (Z < 20) than heavy ones, because heavier elements need higher beam energies to overcome the Coulomb barrier effect.For a given atom/nucleus, gamma rays have higher energies than X-rays and absorption in the target depth probed by the beam particles is normally negligible, that makes the PIGE technique ideally suitable for detection/quantification of low-Z element [1].PIGE often complements PIXE, because it enables obtaining information about the low Z elements, non-detectable by PIXE because their X-rays have too low energy to be detected or are absorbed before reaching the detector [2-3].The main purpose of this study is to use the PIGE method to detect elements in the blood. Due to the presence of iron and heavy elements in the blood, the proton energy is considered to be more than 3 MeV (20-25 MeV). The PIGE method is used. Blood components are extracted from the ICRP report [4]. The relevant data is entered in the MCNP code input file. MCNPX is nuclear code that based on Monte Carlo method [5]. First, the characteristic gamma-ray of each element and iron is identified and then by changing the percentage of iron in the blood, the response of the SiPM detector in this characteristic energy is calculated and formulated. The details of this method will discuss in following.

Experimental
Preparation of the materials and simulation
In MCNP code for calculation of charecteristics gamma-ray an input file is witten which include density and mass percent of blood elements, proton source data,SiPM detector data and its related Tally.The geometry of PIGE method is shown in fig 1.In the fig 1, the target is blood ,the main part of SIPM detector is a scintillating crystal of CsI (Tl)[6] and point source is a proton beam that emitt parallel proton particle toward target. As a result of the proton beam interaction with the target (which is the same blood components),the target nuclides are excited and emit characteristic gamma from each element of the compound. Due to the small size of the target and its proximity to the detector, all emitted gamma-rays reaches to the detector. The detector response is the same energy deposit of the gamma-rays received by the detector crystal which measured in MCNPX with * f8 tally .

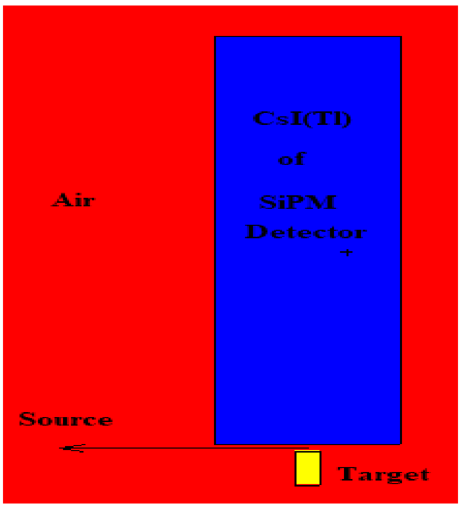

Figure 1:The geometry of PIGE method in vised software

The proton source is located between the target and the detector. The proton source is a source with an energy of 20-25 MeV. MCNP Input file need density of each element exists in blood for detection of characteristics gamma-ray emission in PIGE method. Their densities cannot be the real density due to their poor concentrations. We calculate each density of elements by relative concentration of blood elements. This calculation will describe in full manuscript. To calculate the characteristic gamma lines of each element, the density of that element in the input file is required. The density of elements in the blood is different from the density of each of those elements in nature. According to our calculations the density of each elements in the blood is equal to relative concentration multiply in nature density of elements in the blood. If we put the natural density of each elements in the code, we have a large number of characteristic gamma. But by placing the actual density of the elements in the blood, the number of characteristic gamma decreases, which is important to determine the characteristic gamma lines of each element in the blood. The SiPM scintillator with dimensions of 3×3×3 cm^3 is placed before target. The 10^7 number of particles was simulated for Monte Carlo calculation error falls below one percent.The MCNP code runs on a computer system running Windows 10 with a 2.4 GHz CPU and GB2.3 RAM.To calculate the characteristic gamma spectrum, Tally F8 is used, that calculates the energy remaining in the CsI (Tl) detector at 0-25 MeV to 1keV efficiencies in MeV per particle from the source. In order to perform MonteCarlo calculations we have to ensure the accuracy of the method and its results. For investigation the accuracy of this method, the gamma characteristics of Si element by 9 MeV proton (that is 1.771 MeV[7]) will test.

Results and discussion

This research was done in two steps.First the accuracy of this method was checked.MCNPX result of this step was indicated the gamma characteristic of Si by 9 MeV proton is 1.779 MeV .The concordance percentage of MCNPX calculation validation is 99.6%.After validation in second step the characteristic energy spectrum of iron and blood parameters tested by 20-25 MeV proton beam that is 7.02 MeV. After detecting the gamma-ray characteristics of iron in blood by changing the iron percentage in blood the detector response was calculated for each percent. With changing the percentage of iron in the blood, its density and the percentage of iron in blood also change. Because of iron percent changing in the blood is so low, density remains almost constant but all the percentages of the elements involved are multiplied by a coefficient corresponding to an increase in the percentage of iron in the blood In this gamma-ray characteristic, with changing the Iron percent in blood (η), the response of SiPM (x) was obtained as Equation 1 and Fig 2.

$$\eta = 8E\text{-}17\,(1+x)^{3.5E8} \quad (1)$$

Conclusions

In this research, the PIGE method for detecting Iron in blood using a proton beam with an energy of 20-25 MeV was introduced and was formulated. Using PIGE method, an unknown element or percentage of elements in a sample can be obtained. The results of this test, which is a well-known non-destructive test, does not cause fundamental changes in the irradiated targets and is introduced as an efficient method for detecting elements. Composite nuclei decompose in different ways. One method of decaying composite nuclei is gamma radiation. It is also possible for neutrons and charged particles to be irradiated, and the other is from composite nuclei produced. In this study, the possibility of emission of characteristic gammas by composite nuclei created by the adsorption of protons by different nuclei has been investigated. The results of this test, that is a well-known non-destructive test, do not cause fundamental changes in the irradiated targets and is introduced as an efficient method for detecting elements.

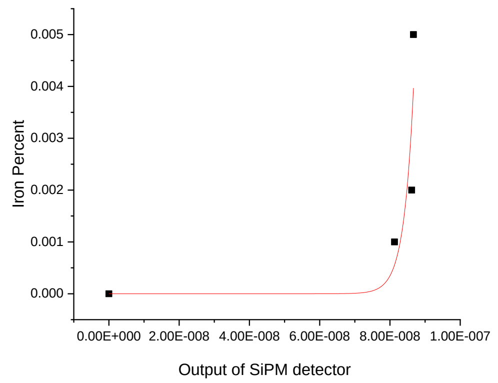

Figure 2: Iron percent in blood versus of output SiPM detector by 20 MeV proton in PIGE method

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