Simultaneous Determination of Iron Pipe Wall and Scale Thicknesses by Prompt Gamma Emission Method

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Abstract

The prompt gamma rays emission, following neutron absorptions are characteristics of material under test and its intensity is proportional to amount or thickness of the material. The method is non-contact, and can, therefore, be very useful for scale or corrosion measurement of high temperature or insulated pipes. This method can be used to identify type of scale if it is not known.

Neutron from ^{241}Am-Be source with an activity of 11.1 x 10^{10} Bq (3 Ci) emitting 6.6x10^{6} n/s were allowed to be incident on carbon steel pipes whose diameters were 10 and 16 cm. These pipes contain asphalt or paraffin scales, likely to be found in oil industry. The gamma spectroscopy system consisted of 20% relative efficiency HPGe gamma detector with 8192 channels multi-channel analyzer and other appropriate nuclear electronics.

The 7.63 MeV prompt gamma rays were clearer among several gamma rays emitted from iron. The single and double escape peaks counts were measured as a function of iron pipe wall thickness for 1 h. The counts were linear with thickness up to the maximum measured thickness of 1.1 cm and expected to remain linear for higher thicknesses because of the gamma rays high energy. For paraffin scale, the H prompt gamma ray main peak of 2.22 MeV was measured as a function of scale thickness for 1 h in 16 cm diameter pipe. Counts were linear with thickness until the pipe was almost filled with scale. Data showed that counts of the iron peak are affected by the amount of organic scale and that for accurate measurements both thicknesses has to be determined simultaneously.

Introduction

Existing corrosion and scale measuring techniques are not successful in measuring corrosion in hot or insulated pipes. They also fail to detect organic scale. The limitations of these techniques are discussed elsewhere [1]. The prompt gamma rays emission, following neutron absorptions are utilized here for the measurements of corrosion and organic scale. The emitted gamma rays are characteristics of material under test and its intensity is proportional to amount or thickness of the material. The method is non-contact, and can, therefore, be very useful for high temperature or insulated pipes applications. Accessibility is needed only from one side of the object to be examined.

The schematic setup for neutron capture gamma rays is shown in Fig 1. Some of the neutrons emitted from the source will be captured by the iron pipe wall and by the organic scale which contains hydrogen and carbon atoms. Following the neutron capture processes several characteristics gamma rays are emitted from iron and organic scale. The most clear gammas ray from iron is the 7.63 MeV and that of scale is the 2.223 MeV from H atoms. Carbon emits 4.945 MeV inelastic gamma rays, but the interaction with carbon atoms is small compared to that with hydrogen atoms (The absorption cross sections at 2200 m/s of H and C atoms are 0.332b and 0.0034b respectively).

In order to increase capture process water was applied on three sides around the pipe under inspection. Some of the fast neutrons from source are moderated and slowed down by water, and some will diffuse backward to the pipe, increasing capture process. These neutrons have higher probability capture because of their low energy compared to those coming directly from the source.

The gamma ray flux ϕ_g following neutron capture for a similar geometry experiment was given by [1]:

$$\phi_g = (1/2)\, \varnothing_{th}\, \textstyle\sum_a [1 - E_2(\mu_s t)]\ \exp(-\mu_i d)$$

Where $\o_{th}$, $\sum_a$, μ_s, μ_i, t and d are the thermal neutron flux at the scale position, the scale macroscopic absorption cross section, the scale gamma linear attenuation coefficient, the iron pipe wall gamma linear attenuation coefficient, the scale thickness and the pipe wall thickness respectively, and E_2 is an exponential integral function given by [2]:

$$E_2(x) = x \int_x^{\infty} (e^{-t}/t)\, dt$$

According to the equation above the gamma ray flux increases sharply with scale thickness, then reaches a saturation value at very large thickness.

Other studies on corrosion and organic scale deposition measurements by neutron capture gamma rays were made Abdul-Majid et al., [3-7] who also used other radiation interaction methods for the same purpose [8, 9]. Ribeiro et al investigated the obstruction of crude oil carrying pipelines by paraffin deposits [10]. San-Miguel [11] studied the effect of corrosion inhibitors on wax deposition. Gunarathne and Keatch [12] studied the dissolution of mineral deposits in petroleum pipelines.

On-line inspection of scale and corrosion was studied by Fujine et al, [13] who used video image processing system for real-time neutron radiography. Dalichow et al [14] studied crack depth measurements in stainless steel pipes while Arney et al studied cement-lined pipes for water lubricated transport of heavy oil [15].

Materials and Method

The neutron sources was ^{241}Am-Be. The activity of the ^{241}Am in the ^{241}Am-Be neutron source was 3 Ci (1.11×10^{11} Bq) with accuracy within ±6%. The neutron emission rate was 6.6×10^6 n/s with a tolerance of ±10%. The associated gamma exposure rate for the bare source was about 7.5 mR/h at 1m, while the total neutron dose rate was 6.6 mrem/h at 1m. ^{241}Am has a half-life of 433 years and decays by emitting alpha-particles of 5.4 MeV followed by Gamma rays of 60 keV. Several gamma rays are also emitted following a neutron emission due to de-excitation of the Be nucleus.

The detector was HPGe of 20% efficiency supplied by Canberra, USA. The associated electronic components includes a power supply (type 2000) a preamplifier (type 1406) an amplifier (type 2012), and an 8192 multi- channel analyzer (pc with special electronic card); all made by Canberra, USA.

The pipes used in the measurement were made of carbon steel with three different wall thicknesses of 4 mm, 8 mm and 10 mm and two diameters of 10 cm and 16 cm. Aluminum pipes each has 1 mm wall thickness of deferent diameters were used to confine the scale inside each iron pipe. Aluminum has small cross section to slow and fast neutrons , it will, therefore, give least interference. Carbon steel consists mainly of iron, with a few percentages of manganese, silicon, copper, aluminum, chromium and traces of other elements. The organic scale was Paraffin ($C_{25}H_{52}$): This is a common oil product material likely to be found as deposit in pipes in oil industries.

Lead blocks, 10 cm thick, were placed between the source and the detector to stop gamma rays coming directly from the source. Lead was also placed underneath the set up to stop capture gamma rays coming from the floor. Water in concrete contains H atoms that would give gamma rays that interfere with the signal to be measured from the H atoms of the organic scale. The system was calibrated for energy by using several known sources such as ^{137}Cs (0.662 MeV), ^{60}Co (1.332 MeV and 1.17 MeV) together with neutron capture gamma rays of H (2.223 MeV), Fe (7.632 MeV) and carbon (4.945 MeV).

Results

Iron Wall Thickness

Counts for one hour of single and double escape peaks for iron 7.63 Mev gamma rays at different iron pipe thicknesses, for 10 cm diameter pipe, are shown in Fig. 2. The relation is almost a straight line because only negligible fraction of this gamma ray is self-absorbed in the pipe wall. At larger thickness of more than 2 cm, saturation effect will start to appear according to eq. 1. In most cases pipe thickness do not exceed 1cm, therefore, practically the relation is linear. Comparison in counts of double escape peaks was made between 16 cm and 10 cm diameter pipes and is shown in Fig. 3. It is very clear that the 16 diameter pipe gave higher reading. This is because there are more iron atoms in the 16 cm diameter, and, therefore, more interactions.

Filling the pipe with water provide more neutron moderation, increasing slow neutron flux at the pipe wall. Because the absorption cross-section is higher for slow neutrons than that of fast neutrons the interaction rate will be higher as well. Fig.4 shows the 7.63 MeV double escape counts for the cases when the pipe is surrounded on three sides with water and when it is filled with water in addition. The effect of increased moderation is clear.

Organic Scale Measurements

The hydrogen 2.22 MeV was utilized for the measurement of paraffin scale. Counts of the primary peak at different scale thickness inside 4 mm wall thickness, 16 cm diameter carbon steel pipe are shown in Fig. 5.the relation is linear because the paraffin gamma ray attenuation coefficient is very small. The single and double escape gamma ray intensities of iron are affected by presence of organic scale since with more scale, slow neutron flux will be higher at the pipe wall position. Counts of iron single escape peak of 16 cm diameter, 4 mm wall thickness pipe at different paraffin thickness is shown in Fig. 6. This lead to the conclusion that corrosion or scale measurement will not be successful if there is corrosion associated with organic scale accumulation.

Discussion and Conclusion

Neutron capture gamma ray was successful for measuring pipe wall thickness and organic scale accumulation inside pipes. Because it is non-contact it can work on hot, cold or insulated pipes. The method can be utilized for identification of type of scale; it was used before for identification of sulfate and carbonate scales found at desalination plant.

The work was performed using, mainly, laboratory equipment. For field work a compact, easy to carry portable system is available commercially. It is also possible to design a counting system based on single or two windows to make measurements easier. Counting time for one hour is considered long and may be impractical for field work. Time can be reduced ten fold (to 6 minutes) by using higher activity neutron source of about 30 Ci.

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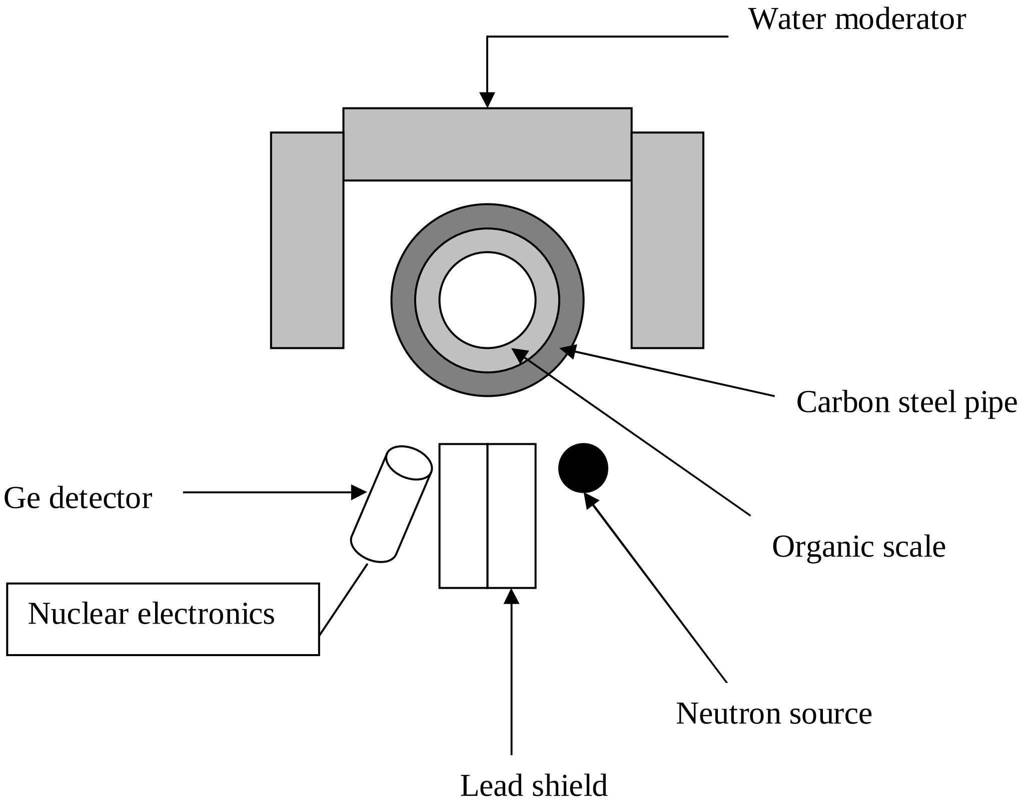

Fig. 1. Experimental set-up for neutron capture gamma ray experiment

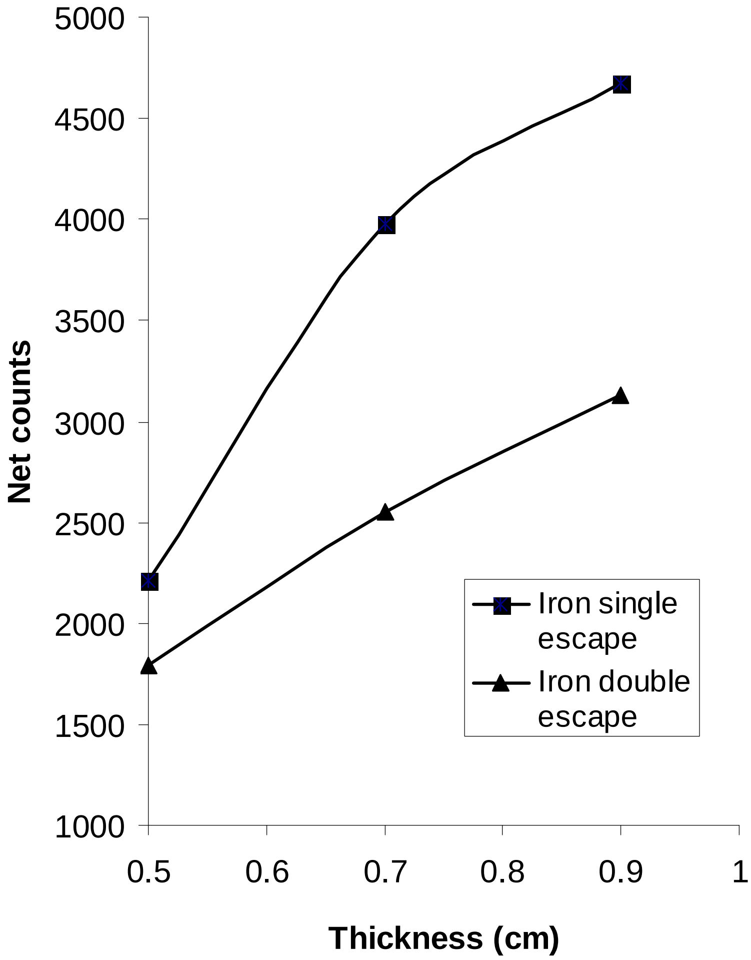

Fig. 2 : Counts for 1 hr of iron 7.6 MeV gamma ray single escape and double escape at different iron pipe thicknesses; pipe was surrounded on 3 side by water, using ^{241}Am-Be source

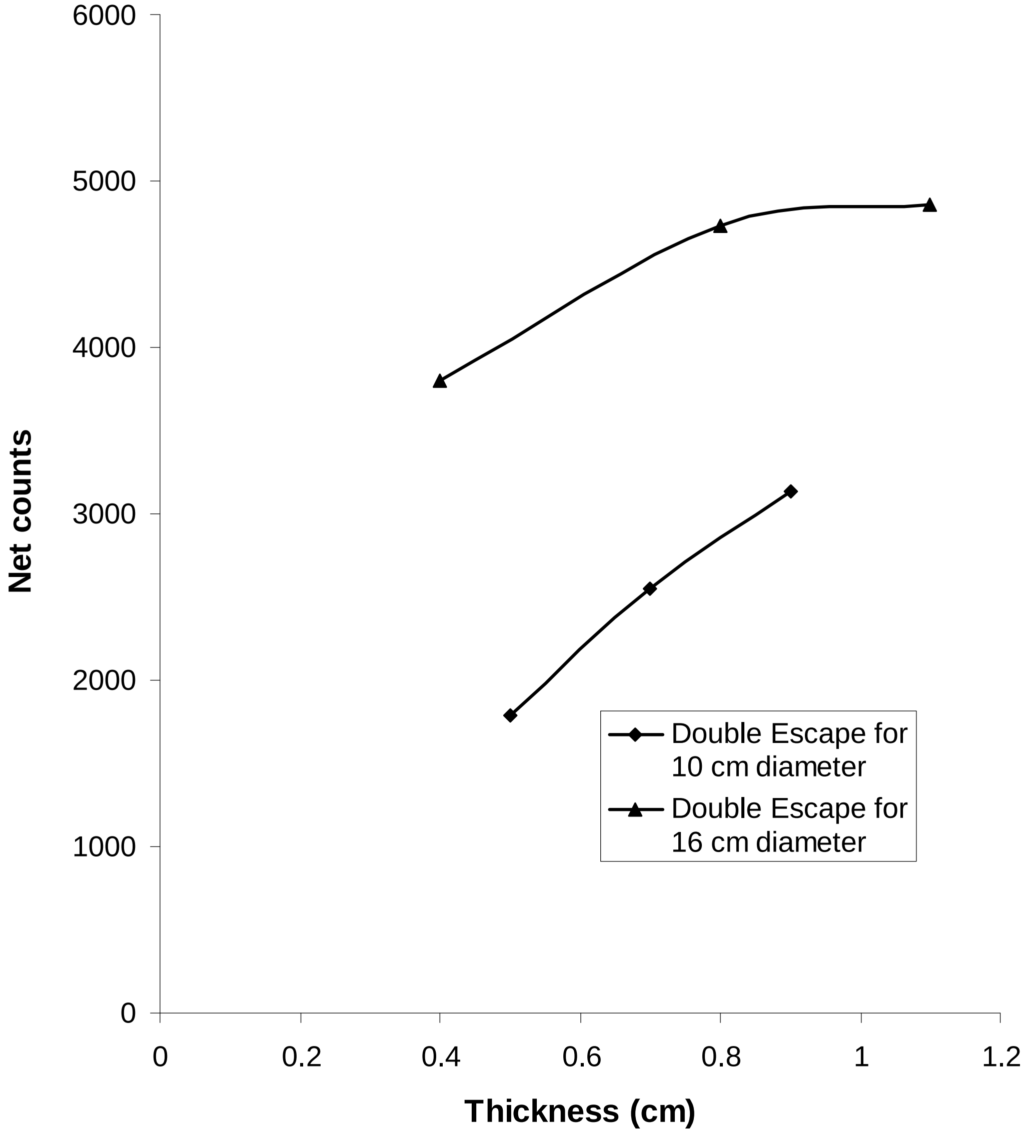

Fig. 3 : Counts for 1 h of double escape Iron 7.63 MeV gamma ray peak at wall thicknesses of 10 cm and 16 cm diameter pipes using ^{241}Am-Be source. Pipe was surrounded on 3 side by water.

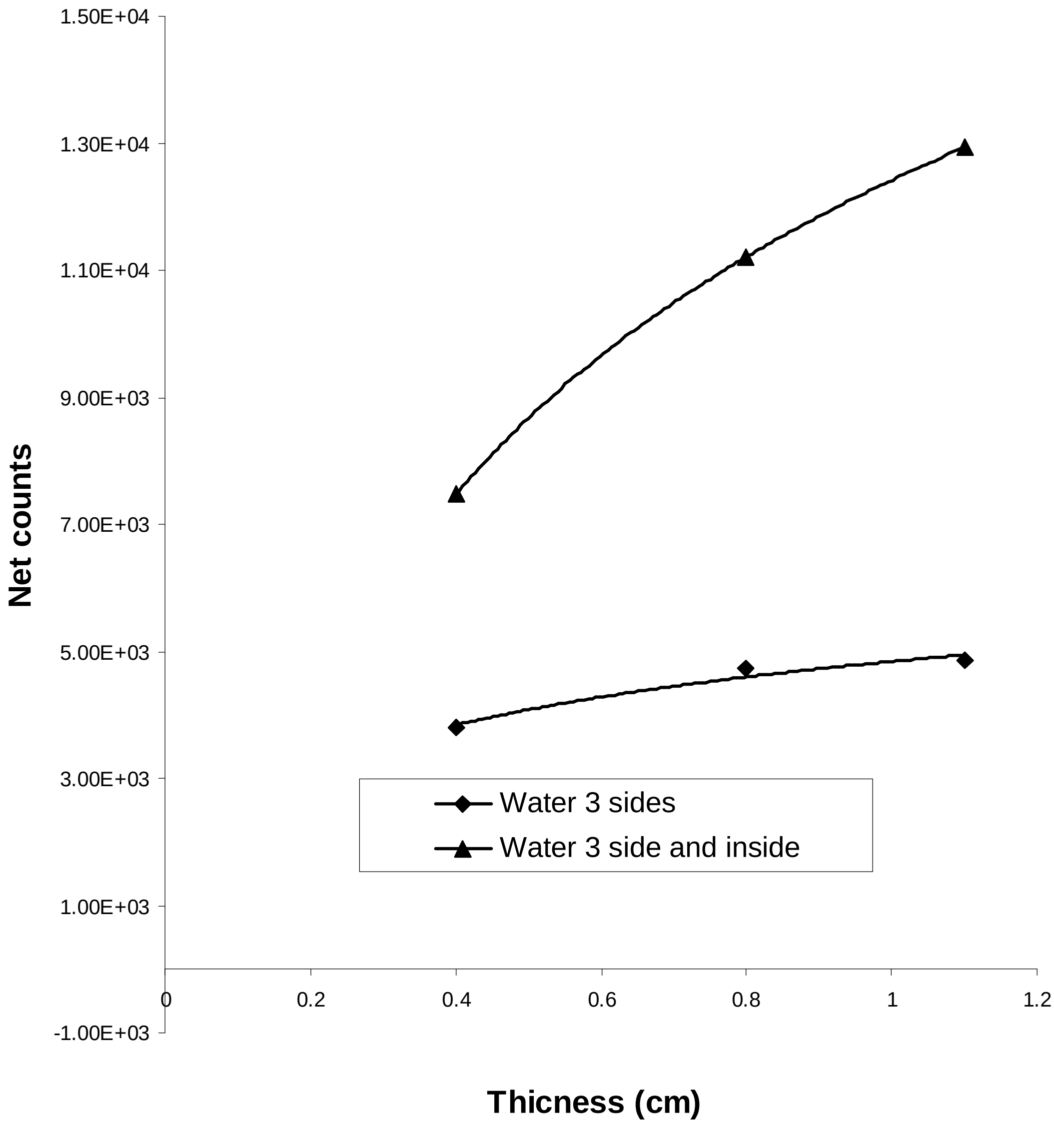

Fig. 4 : Counts of iron 7.63 MeV gamma ray double escape for 1h of 16 cm diameter pipe filled with water and for pipe filled and surrounded from 3 sides by water, using ^{241}Am-Be source.

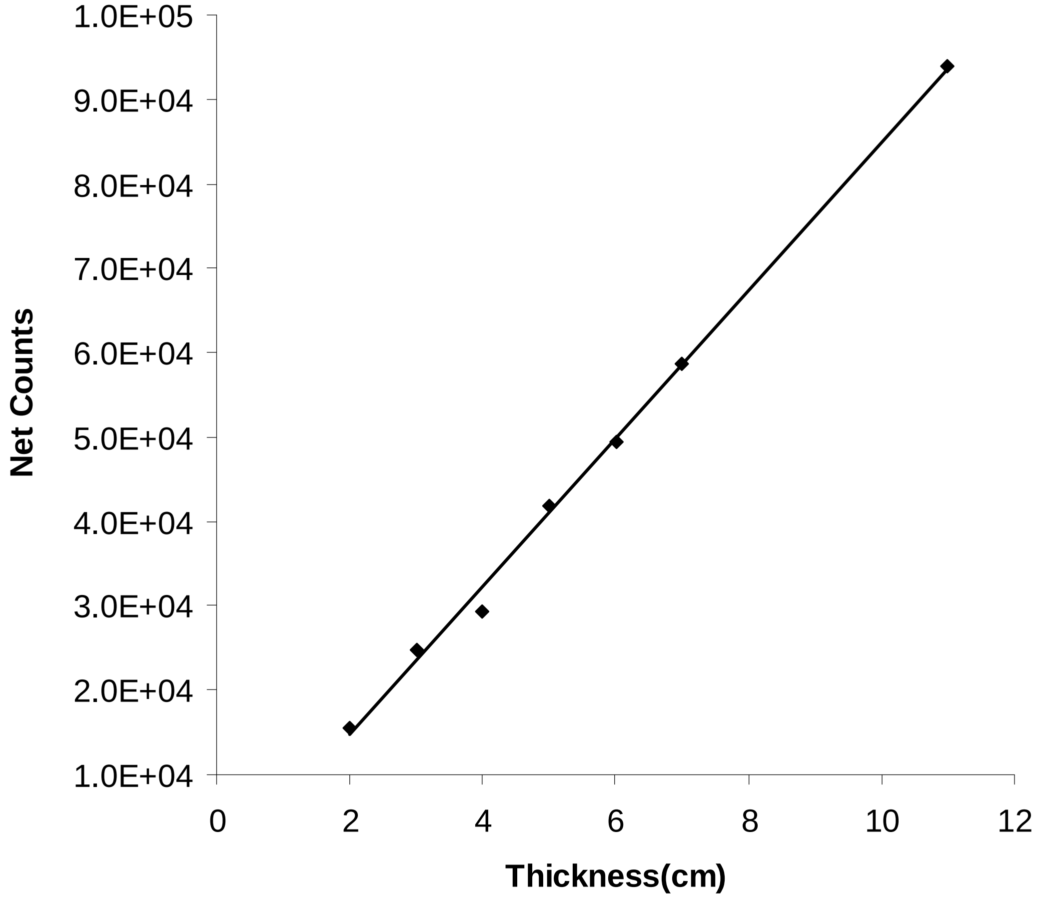

Fig. 5 :Counts for 1h of hydrogen 2.22 MeV gamma ray at different paraffin scale thicknesses, using ^{241}Am-Be source.

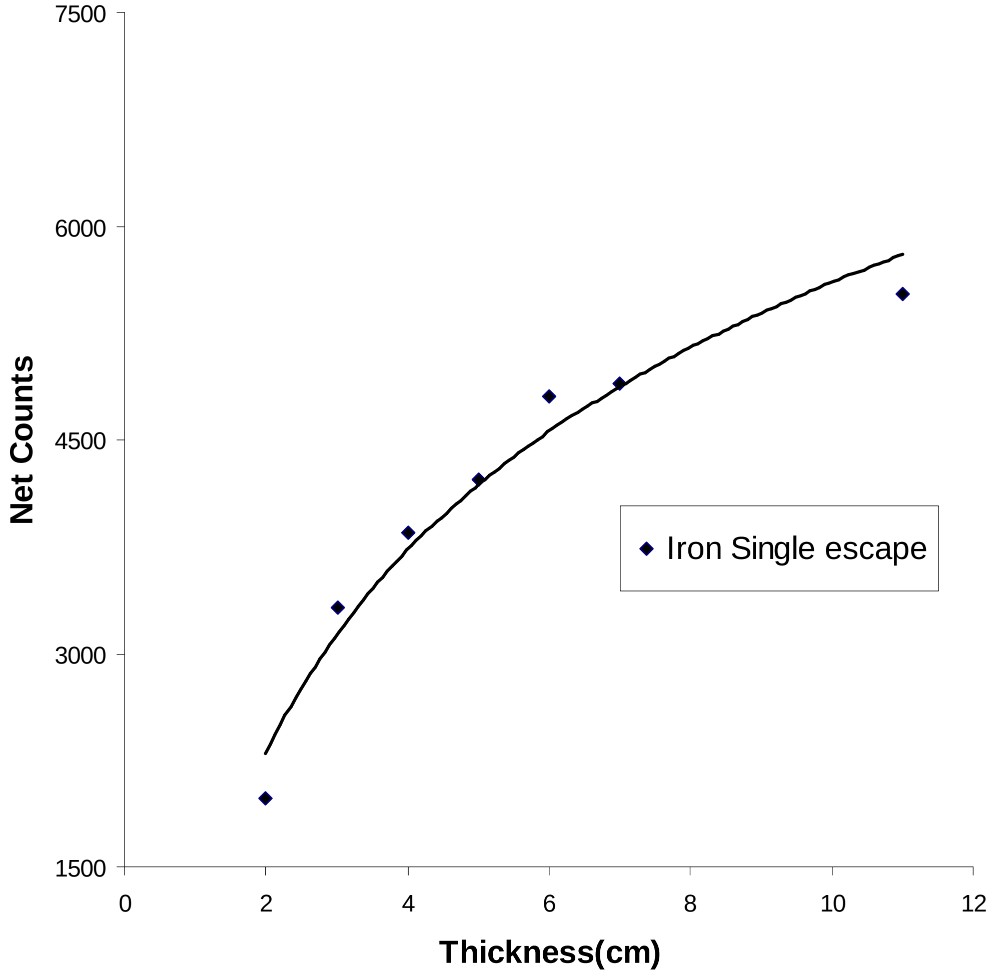

Fig. 6 :Counts for 1 hr of iron 7.63 MeV gamma ray first escape of 4 mm wall thickness pipe at differnt paraffin thicknesses, using ^{241}Am-Be source.