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Use of Gamma Ray Back Scattering Method for Inspection of Corrosion under Insulation

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Abstract

Corrosion under insulation is difficult to measure by the available techniques of ultrasound and gamma or x-ray radiography. In this work a Lab experiment was performed that simulate a real case where pipe corrosion (wall thinning) was measured by backscattered gamma rays.

A collimated gamma ray beam of 1 cm diameter from 10 mCi ^{137}Cs source was allowed to be incident on carbon steel pipes. The pipes were having different wall thicknesses and different diameters and were wrapped with about 5 cm commercially available insulator. The beam penetrates the insulator without significant interaction. Upon interaction with the pipe wall the scattered radiation, due to Compton process, was measured by 2x2 NaI(Tl) scintillation detector located beside the source. Because gamma ray energy of scattered radiation depends on the angle of scattering, which was kept constant, all gamma ray photons reaching the detector were having the same energy.

The backscattered radiation made very clear and well resolved peak on the multi-channel analyzer. Counts under the peak versus wall thickness showed almost linear response up to more than 1 cm wall thickness. The small increase in counts from the insulator are constant can be considered part of the background since corrosion takes place in the pipe only.

Data showed that a fraction of a millimeter change in thickness can be detectable for 2 min counting time. This can be improved by extending the collection time or by using a stronger source. This method is non-contact, therefore can be used at any pipe temperature. The counts were, relatively, insensitive to pipe wall diameters; this may be an advantage because it makes the calibration process much easier. On the other hand the counts were sensitive to change in distance between the pipe and the detector.

Because the activity used was only few mCi, the system is much safer to use compared to gamma radiography where source strength of about 100 Ci is usually used. The exposure rate was very close to background at about 1 m when the beam was open.

Introduction

An appropriate pipe corrosion monitoring system would reduce the number of pipe failure and plant shut-down. It would also make better utilization of existing components because during routine inspection pipes are sometimes replaced even though they still have lifetime.

In this work gamma backscattering method is used for pipe corrosion measurements. It is non-destructive and contactless procedure, therefore, can be used for pipes at, essentially, any temperature.

Measurement of corrosion in insulated, very hot or very cold pipes by conventional methods has limitations. The ultrasonic technique cannot be used on hot or cold pipes or if surfaces are not prepared and the technique so far, is unsuccessful for insulated pipes. With X-ray or gamma ray radiography excess has to be made on both sides of the pipes. Moreover the results of the tests are not immediately available.

Abdul-Majid used the method for scale determination and general and, localized corrosion in desalination plants, and for density and thickness of polymers [3]. Thickness measurements are given by Oyedele [4] and Mohammadi [5]. The density was studied by the same method by Huddleston et al [6, 7] who utilized single and multiple scattering. Ohkawa [8] used the technique for the measurements of voids in materials, while Mudahar and Sahota [9] used it for the determination of soil density and water contents. For materials contents and analysis Confalonieri et al [10] used it in the analysis of binary alloys, Charbuchinski [11] for determination of ore properties and Teller [12] for measurements of sulfur in crude oils and lead in refinery products. Some other applications include determination of hold-up in slug flow [13], root activity measurements [14], location of termite damaged railway sleep [15], relative density measurements in lung phantom [16] and the determination of effective atomic number of material [17]. For study of the basic interaction properties Cardwell and Cooper [18] investigated the directional Compton profile measurements of aluminum while Ozmutla [19] measured the differential cross-section of NaI at 59.9 keV.

Experimental

The method is explained with reference to Fig. 1A. Collimated gamma-ray beam is allowed to be incident on the wall of the pipe. Its energy can be selected high enough that attenuation in the insulator is insignificant. The gamma ray energy selected in this work was 0.662 MeV. The mass attenuation coefficient at that energy for Fe and most other materials of intermediate atomic number is around 0.07-0.08 cm^2/g. At insulator thickness of about 5 cm and density of about 0.2 g/cm^3, the intensity of ^{137}Cs source reduces by about 4% when passing through the material. This is equivalent to change in iron thickness of about 0.6 mm. But because the attenuation in insulator is constant and not available, it is not going to create any interfering effect on measurement of iron wall thickness. Upon reaching the iron wall the original intensity will reduce with thickness of iron exponentially.

The Compton scattered beam will have energy E' given by

$$E' = \frac{EE_c}{E[1-\cos(\pi-\theta/2)]+E_c}$$

Where E_c is the rest mass of electron = 0.511 McV.

The backscattered beam will undergo divergence as well as attenuation in its way to the detector. Therefore the intensity will undergoes double attenuation. If the geometry if fixed, the backscattered radiation will show a wide energy spectrum as shown in the Fig. 1A. The count rate in the detector is expected to change with thickness following the relation [3]:

$$C = K_1 \{ 1 - \exp [- (\mu + \mu')t]\}$$

Where C is the count rate, K_1 is a constant and μ and μ' are linear attenuation constant of incident and scattered beams. Counts should increase with thickness until saturation is reached. If wall thickness is at or greater than the saturation thickness, which is controlled by $(\mu + \mu')$, changes in iron wall thickness cannot be easily detected. When working with high density material, higher energy source should be selected that has small value $(\mu + \mu')$ and vice versa. For iron the 0.662 Mev of ^{137}cs is quite useful for thickness up to about 2 cm. For thicker iron wall ^{60}Co or ^{22}Na should be used. For materials like aluminum or polymers a source like ^{228}Th of 0.084 Mev and 0.241 MeV or ^{241}Am of 0.06 MeV can be useful.

An alternative approach is the use a point source mounted on the detector as shown in Fig. 1B. The gamma ray spectrum will be as shown in Fig. 1B. Because the detector can see both, incident and scattered radiation two peaks will appear. At this arrangement the detector response follows the relation [3]:

$$R = \frac{K_2}{(\mu+\mu')}[1-E_2\{(\mu+\mu')t\}]$$

Where K_2 is a constant and E_2 is an exponential integral function of second order whose volues are found in literature [20]. In this relation saturation is reached faster than the exponential function. The backscattered peak will be small compared to the main peak. And if higher activity source is used, the dead time and pulse build-up may prevent the detector from functioning properly. In this geometry the backscatter radiation will be coming from larger area of the pipe wall and small localized corrosion can be easily missed. On the other hand much lower activity sources of order of μCi can be used with no lead shield is required.

The experimental arrangement utilized the geometry shown in Fig. 1A. A 5.08 x 5.08 cm NaI (Tl) scintillation detector with power supply coupled with pro-amplifier, amplifier and a PC computer with special electronic card to make a system of 8192 multi-channel analyzer. The source was about 10 mCi ^{137}Cs surrounded by leaded blocks with small opening facing the pipe of about 1 cm in diameter. Carbon steel pipes of different diameters and wall thicknesses were used. The insulator was a commercially available type of few centimeters in thickness coverall by the aluminum sheet.

Results

With carbon steel pipes of 20 cm in diameter counts, for 3 min were taken at different pipe wall thicknesses, the results are shown in Fig. 2. Counts increases with wall thickness increase and approach saturation at large thickness. It is expected that at this gamma energy the system can successfully used up to about 2 cm of pipe thickness. Between a thickness of 7 mm and 9 mm the system gave 900 counts mm. Knowing that one standard deviation at this counts is 130, a small fraction of a mm should be detectable. If higher accuracy is needed counting time can be increased or a stronger source can be utilized.

The attenuation of radiation in the insulator is negligible. With thicker insulator attenuation would increase. Insulator will not constitute any interfering factor as its attenuation is constant and changes are taking place in the wall thickness if corrosion occurs.

When pipe is filled with water noticeable change in counts was observed. Therefore, in real situation the inspector should know if the pipe contains liquid or not when tests take place. If this is difficult to get an alternative more complicated detection system contains level gauge can be designed.

The counts versus thicknesses of pipes of 16 cm and 10 cm diameters are shown in Figs. 3 & 4. The same trend as that of 20 cm is observed with almost same saturation thickness. It can also be observed that pipe diameter has little effect on the backscattering counts. This is obvious as the beam is hitting the same pipe area.

Discussion and Conclusion

Gamma-ray backscattering method can be used successfully for measuring corrosion in insulated pipe. The method is quite sensitive for small change in the thickness of pipe wall. The sensitivity can still be improved by using a stronger source. With ^{137}Cs the pipe wall thickness has to be less than about 2 cm in order for the system to work properly. Most pipes in industry have wall thickness that dos not exceed about 1.5 cm. For higher than 2 cm thickness more energetic source can be used, while for pipes made of aluminum or plastic lower energy source is preferred as it gives higher sensitivity. The half-life of the source has to be more than about 1 year to have a practical inspection system. With shorter half-life frequent calibration is needed. Higher energy sources of long half-life in addition to ^{137}Cs are ^{22}Na and ^{60}Co. The use of multi-energy source is useful for multi layer pipes, or if high sensitivity is required at both low and high thicknesses. ^{152}Eu is a very useful multi-energy source of 13.33 years half-life.

The activity of the source used here was about 10 mCi. This is 10,000 times smaller than sources used in radiography. The radiation exposure is therefore, much lower.

In this technique the measured thickness is averaged over 1 cm diameter circle, the area of the beam hitting the pipe. If it is desirable to have more detailed information on localized corrosion narrow gamma beam need to be used with higher activity source.

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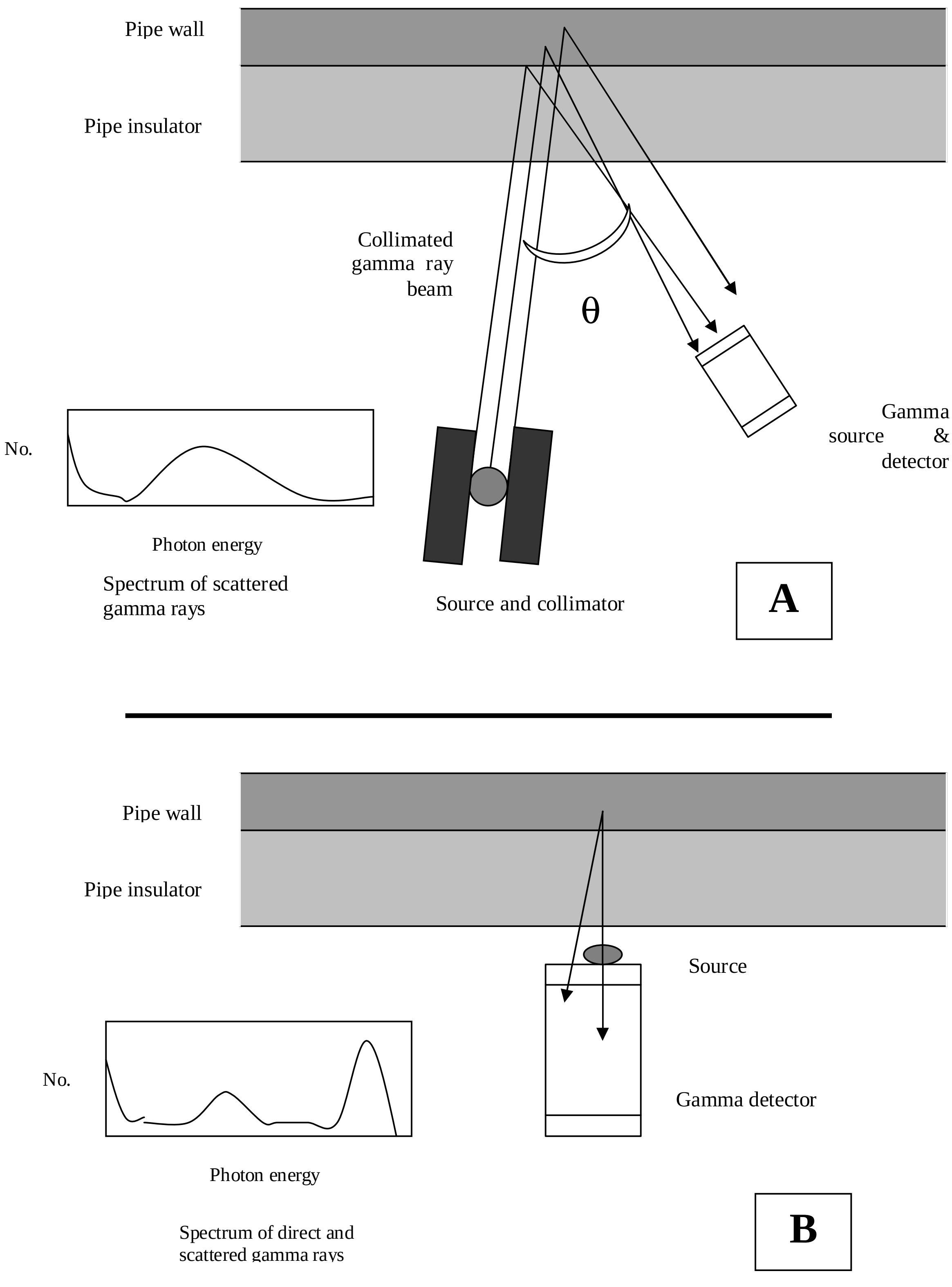

Fig. 1. Collimated beam [A], and point source [B] backscattering gamma ray setups

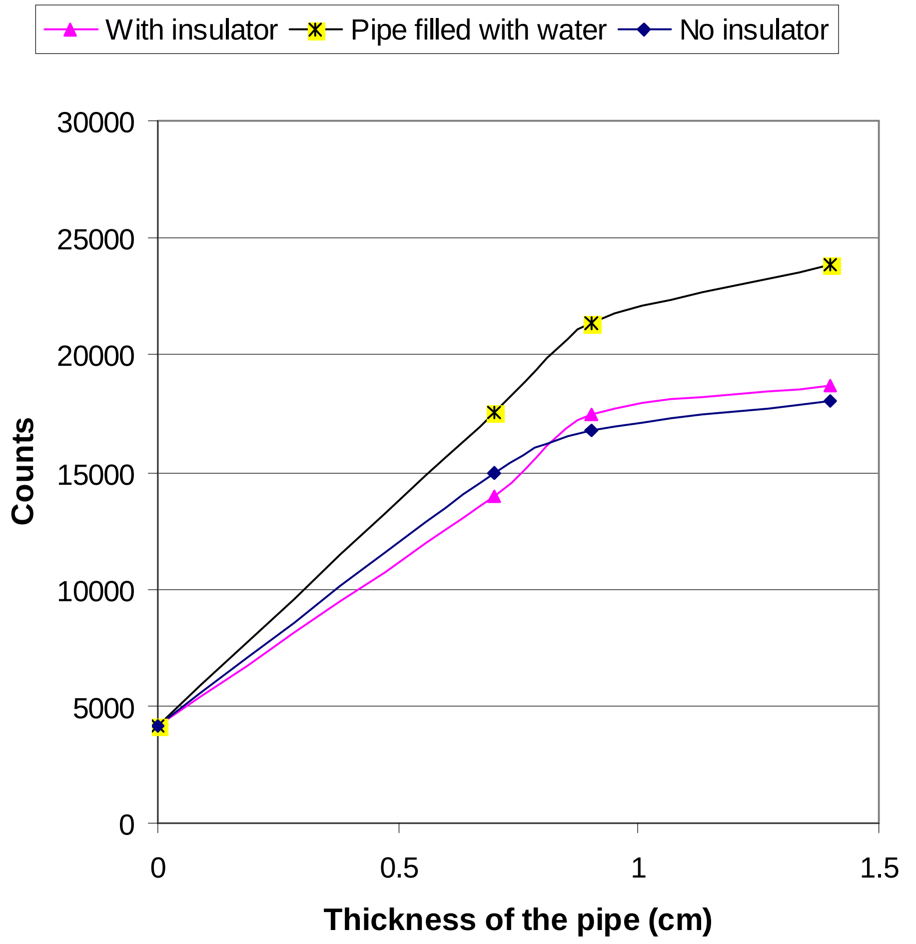

Fig. 2. Counts for 3 min. at different pipe wall thickness of 20 cm diameter pipe.

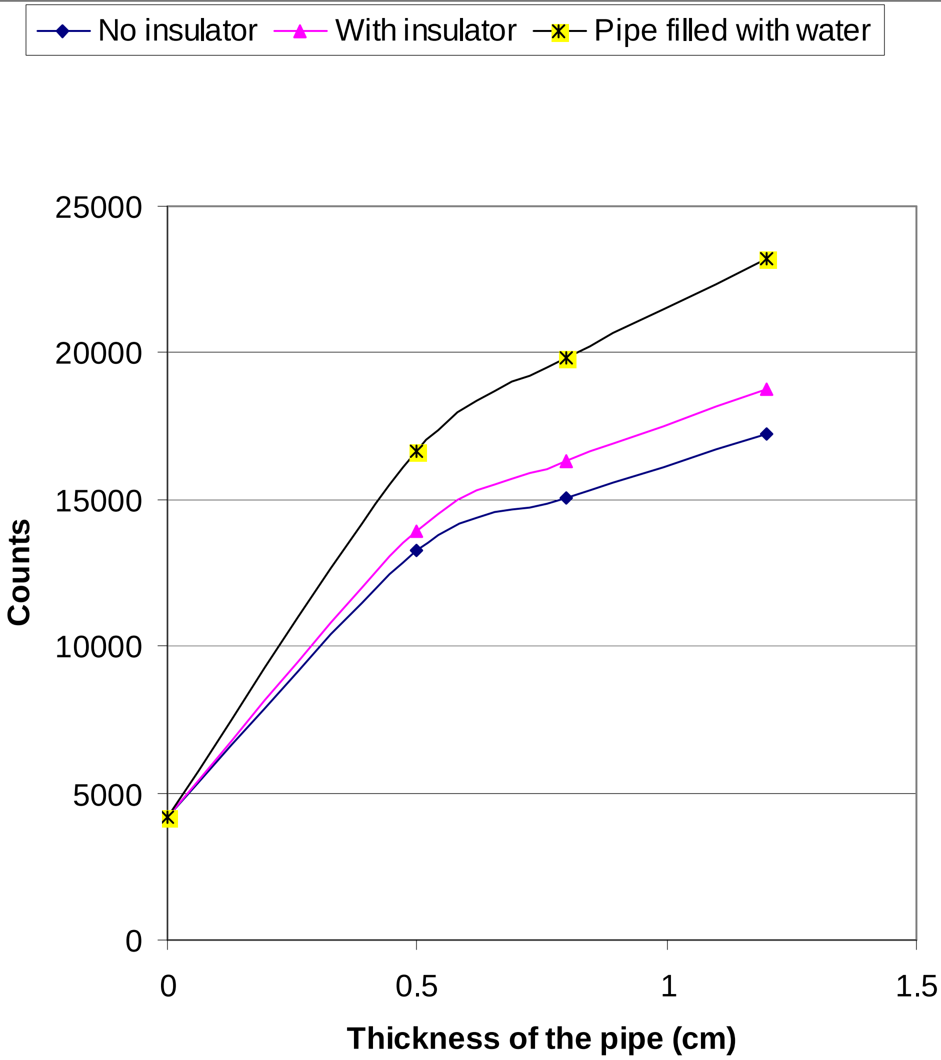

Fig.3. Counts for 3 min at different wall thickness of 16 cm diameter pipe.

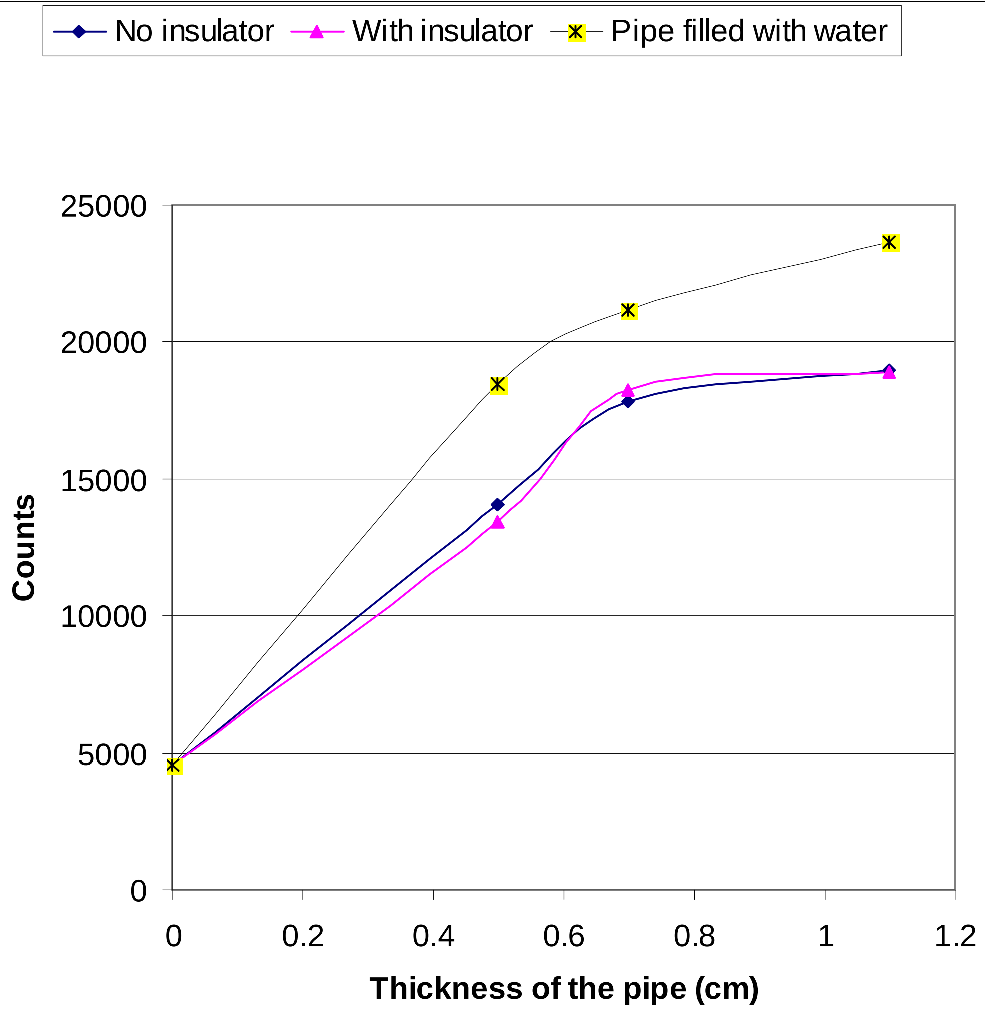

Fig. 4 . Counts for 3 min at different pipe wall thickness of 10 cm diameter pipe.