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Detection the Corrosion in Pipes by Compton Back Scattering Technique

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ABSTRACT

The multiple Compton backscattering (MCBS) technique has been used to investigate the detection and imaging corrosion under the insulation pipe. An energy source with a mono – energy 0.662MeV of ^{137}Cs has been used. Gamma ray photons have been allowed to be incident vertically on the insulator pipe whose outside diameter, wall and asbestos insulation thickness are (28, 1, 4)cm respectively. The steel pipe has a corrosion defect with a diameter (8) cm. The count rate of scattered γ – photons with scattering angle in the range (130 – 140) degrees has been collected by NaI(Tl) detector with different radius. Assuming the source and detector locations are in the same side from the pipe. Monte Carlo simulation has been written in FORTRAN95 language programming to follow the history of photons.

This study provides the ability of this technique to detect and imaging the corrosion under the insulator pipes. The radius of detector which gives good results for corrosion detection and imaging is 6cm among five different selected radius.

Keywords: Compton backscattering; corrosion detection; gamma – ray interaction; nondestructive technique; pipes.

الكشف عن تأكل الانابيب باستخدام تقنية التشتت الخلفي لكوميتن

الخلاصة

لقد تم استخدام تقنية التشتت المتعددة الخلفي المتعدد لكومبتون للتحقق من الكشف وتصوير التآكلات التي تحدث في الانابيب وتحت العوازل. ان الترتيب الهندسي لهذه التقنية يتطلب استخدام مصدر لفوتونات أشعة كاما (عنصر السيزيوم ^{137}Cs) وبطاقة احادية 0.662ميكا إلكترون فولت. يتم اسقاط فوتونات أشعة كاما عموديا على سطح انبوب قطره الخارجي وسماكة جداره وسمك طبقة الاسبستوس العازلة هي (28، 1، 4)سم على التوالي، بالاضافة الى وجود عيب تآكلي بقطر 8سم. استخدم كاشف ايوديد الصوديوم المطعم بالتاليوم NaI(Tl) وبانصاف اقطار مختلفة لجمع او تسجيل فوتونات كاما المستطارة بزوايا تتراوح ما بين (130 الى 140) درجة. هذه التقنية تفترض وضع كل من المصدر والكاشف في نفس الجانب من الأنبوب. استخدمت لغة فورتران95 في كتابة محاكاة مونت كارلو لتتبع مسار الفوتونات من لحظة انبعاثها من المصدر ولغاية وصولها وتسجيلها في الكاشف.

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هذه الدراسة اثبتت قابلية تقنية التشتت المتعددة الخلفي لكومبتن في كشف وتصوير التآكل الذي يحدث في الانابيب بالرغم من وجود المواد العازلة عليها، واختيار الكاشف بنصف قطر 6سم اصغر نصف قطر كاشف يعطي نتائج كاملة وواضح في كشف وتصوير التاكل من بين خمسة انصاف اقطار تم اختيارها في هذه الدراسة.

INTRODUCTION

Piping is a common feature in industries. It provides the most economical, safe and efficient way of transporting chemicals in the form of liquids and gases from point to another. As a result, a large amount of piping construction has been carried out in the world. A considerable proportion of piping is used in power stations, petroleum and chemical plants in transporting water, steam, petroleum and chemical products at moderate or high temperatures. This piping is usually covered by thick insulation materials, such as asbestos, nylon cloth, concrete or lime. Because pipe experiences degradation with time due to the transported media usually has high pressure, poisonous and combustible characteristics, which if not detected might create problems such as leaks or explosion will finally cause pollution, casualties and immense economic loss. Corrosion, erosion, deposits and pipe blockage are some of the possible causes for this [1, 2].

As a result, a nondestructive testing (NDT) technique which can conveniently be used in the field, and which can quantitatively express the corrosion status of steel structures under insulation, would be highly desirable [3].

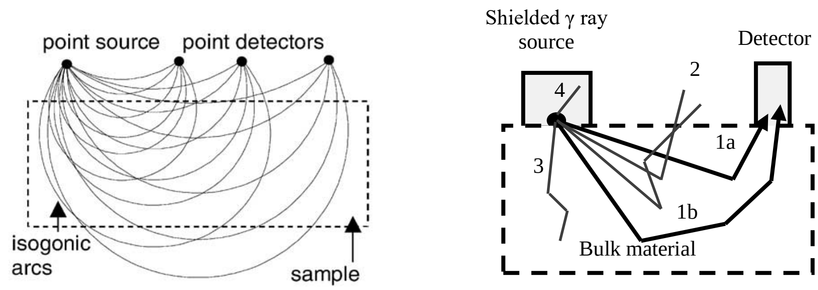
The (NDT) technique investigated in present work is gamma backscattering method for detecting corrosion in the pipeline, because it has the following features attractive for on – site structural crack detection: (1) It is a nondestructive and non – contact method; (2) It can detect a crack below the surface; (3) It is not susceptible to surface roughness and material properties, except their densities; and (4) The source and detector can be located on the same side of the object, enabling testing of massive extended structures [4] .

Asa'd (1997) [5] measuring the wall thickness of steel sections also by Compton backscattering. Khiem and Khai (2000) [6] developed a Monte – Calro simulation to describe the interaction processes of gamma rays when coming in a medium and register the backscattered events are used to reproduce the shape of defects existing in the testing material, whereas Sheng (2002) [7] used the same method to detect the buried landmines. Naito and Yamamoto (2009) [4], successfully detected crack below deposit by using X – ray backscattering technique. Abdul – Majid and Tayyeb (2005) [8] and Abdul – Majid and Balamesh (2012) [9] used gamma ray backscattering method for inspection and imaging corrosion under insulation. Grubsky and et al. (2013), describe Compton imaging tomography (CT) for reconstructing complete three – dimensional (3D) internal structure of an object, based on acquiring multiple Compton scattered X – ray images of object cross sections, and find the benefits of the backscatter X – ray from one – side operation, provides true high resolution 3D topographic data and allows inspecting deep layers of a structure [10].

The aim of this work is to detect and image the corrosion under insulating pipes in nondestructive inspection through using multiple Compton back scattering technique. The principle of this method depended on the Compton scattering for multiple scatter of γ photons through examine an algorithms dependent on the mass absorption coefficients and the area of corrode and non – corrode region of the pipe materials by Fortran Monte Carlo simulation.

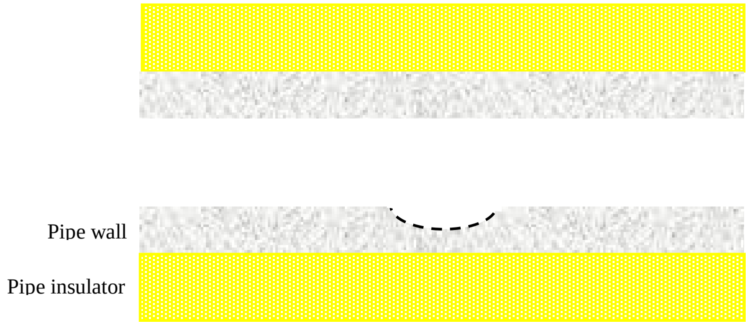
The Geometry Technique

The principle of (MCBS) technique assuming the scattering region has been confined to plane, then for a point source and detector, suggests that any scattered energy (É) corresponds to a precise angle (θ_{Comp}) that define a circular "isogonic" arc of possible scattering locations. Measuring over many energies at several detector locations produces an intersecting mesh of isogonic arcs as shown in Figure 1 – a [11]. The functioning principle of Compton scattering imaging and the shielding of the source prevents photons reaching the detector directly is given by Figure 1 – b [12].



Figure(1): (a) Mesh of isogonic arcs defined by point source and detectors[11] and (b) Single and multiple gamma backscattering principle, where photons emitted from the source are either: (1) detected having undergone single (a) or multiple (b) scattering in the material, (2) lost though the surface by single or multiple scattering in the material, (3) lost by scattering and absorption in the material, or (4) stopped by the source shielding [12].

Figure (2), illustrate an iron pipe used in the present work with 140cm long, 28cm outside diameter (26 cm inside diameter) and 1cm wall thickness, with defect on its inside surface has a shape close to a circular with corrosion diameter (CD) of about 8cm. The pipe has asbestos insulator of 4cm thickness, which is neglected in the calculation due to its low atomic number and density material. Moreover, the backscattered radiation from the insulator is almost constant along the pipe; corrosion takes place in the pipe wall. Hence, it will cause no significant interference.



Figure(2): The specimen pipe.

The geometry of (MCBS) technique employed in this work is illustrated in Figure 3. Where, a point source of gamma ray locates at a distance 8cm from the pipe surface. The gamma photons which is incident perpendicular on the pipe surface, suffer scattering or multiple scattering after interaction with the pipe material. The Compton scatter angle (θ_{Comp}), which studying in this work, is in the range 130 - 140degree with average angle 135degree. Therefore, the scattered photons will be detected by the detector separated by 7cm far from the source. The point source of γ – ray selected is ^{137}Cs with mono – energy 0.662MeV. The NaI(Tl) scintillation gamma detector has been used with different radius (RD = 3, 4, 5, 6 and 7)cm. Each of source and detector have been shielding by using lead (Pb) to prevent registering the photons that come directly from the source without passing in the material, also both of them located on the same side from the pipe surface.

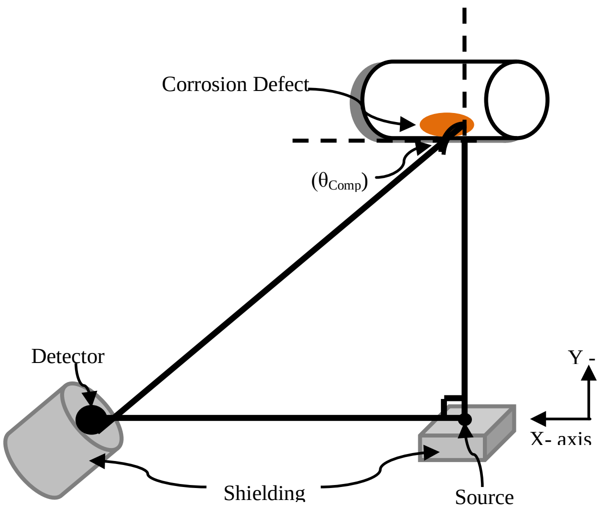


Figure (3): The Geometry Technique.

The Algorithm of Monte Carlo simulation

The algorithm of this work has a main program for the data preparation and interpolation, which has two main subroutines for non – corrosion (iron Fe area) and corrosion (iron oxide Fe_2O_3 area).The histories a large number of photons emitted from the source are followed by using Monte Carlo simulation through Fortran95 language to determine the distribution of the backscatter radiation. A random number (ν) is used to obtain a uniform distribution within the range ($0 \le \nu \le 1$). Simulation of a photons history requires the following procedure:

1) Supposing the pipe material consists of Fe and Fe_2O_3 to simplify the simulation required.
2) The area divides into 70 sectors along the pipe and 25 sectors over the width with an increment of 0.2cm respectively. The corrosion area had been calculated implicit with sectors from 16 to 55 in length and from zero to 20 sectors in width, as illustrate in Figure 4. Hence these data could be fed into the initiated program otherwise to detect the corrosion area.
3) The values of mass attenuation coefficients (μ) related to the energy range from 1keV to 1MeV, has been collected from XCOM [13], for iron and iron oxide, respectively. The collected data had been used in the initiated to develop the interpolation function.

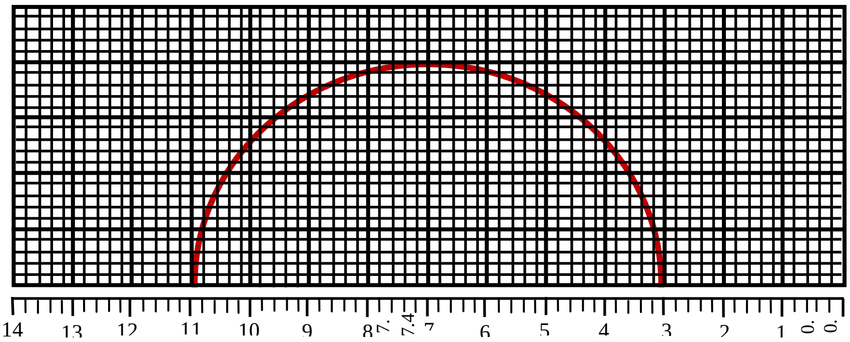


Figure (4): Block diagram of pipe area.

4) In polar coordinate, a photon with incident gamma energy (E_o) is emitted randomly as function of polar angle (θ_{Ph}) and azimuthal angle (φ_{Ph}). Cosine – sampling has been used for the polar angle θ_{Ph} and uniform sampling for the azimuthal angle φ_{Ph} [14]:

$$\theta_{Ph} = \cos^{-1}(2\nu_1 - 1) \quad \text{--- (1)}$$

$$\varphi_{Ph} = \pi\nu_2 \quad \text{---- (2)}$$

5) The energy of scattered photon is obtained using Khan Method [13]. This method is used for random numbers sampling as shown in Figure 5.
6) The polar angle (θ_{Comp}) of scattered photon is given by Compton formula [14, 15]:-

$$\cos\theta_{Comp} = 1 - \left(\frac{1}{\acute{E}} - \frac{1}{E_O}\right) m_O c^2 \quad \text{---- (3)}$$

where E_O and É are old and new energies and $m_Oc^2 = 0.511$MeV.

7) Sampling for the actual path length (PL) of the photon in the material, is given by [14]:

$$PL = -\frac{1}{\mu(E)}\ln(1-\nu_8) \qquad ---- (4)$$

8) For multiple scattering of photons the program which has been installed in this work could be transform to different subroutines for determine the new scattering angles (α, β, γ) through the initial unit vector (n).

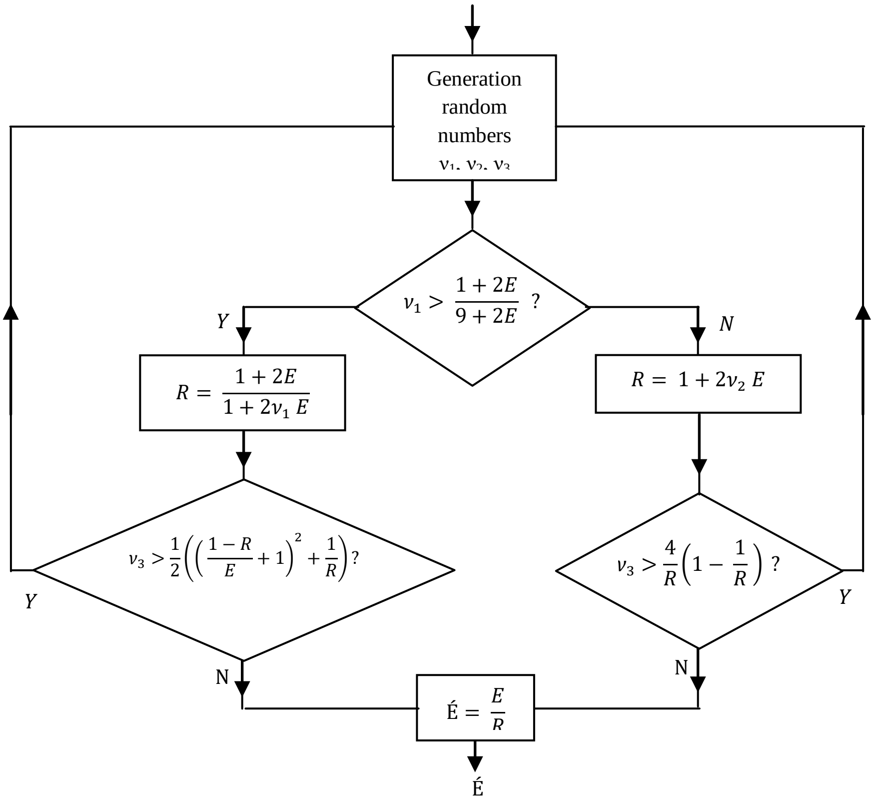
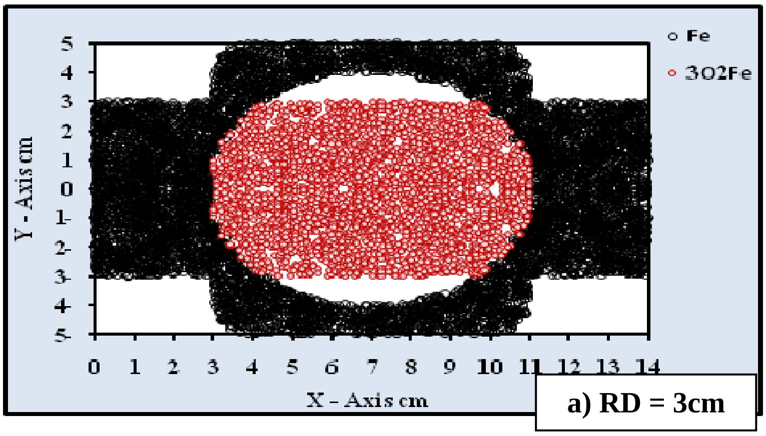


Figure (5): Kahn method used for random sampling of the Klein-Nishina distribution. ν_i are random numbers uniformly distributed in the range $0 \le \nu_i < 1$, E and É are the initial and final photon energies (in units of the electron rest mass energy), and R is the ratio E/É [14].

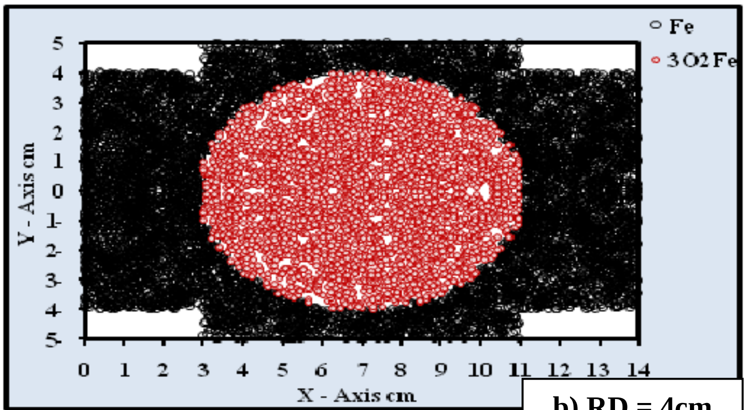
Results and Discussion

For detecting corrosion in the pipe and imaging it's, divided the area pipe into many sectors to source and detector can be scanning the whole area of the pipe, which is in the plane (X, Y). The range of scanning is 0.2cm and at each scanner movement, the photon history from its projection until detect or register by detector is simulated by the above procedure. Notice that the count rate of back scatter photons will be drops when scanning in the location having corrosion. So, after complete scanning area of the pipe can get an image in two dimensions (2D) of the corrosion. This is illustrate in Figure 6 – (a, b, c, d and e) that show images in 2D of circular corrosion (Fe_2O_3) in the steel (Fe) wall pipe for different radius of detector. On these Figures, the black circles (or points) indicate to back scattering photons from Fe location and red circles (or points) are from Fe_2O_3 location.

Also, these Figures shows the count rate of register back scatter photons increase gradually when increasing the radius of detector from 3cm until 5cm, as see in Figures 6 – (a, b, and c), whereas, the count rate will be constant from radius 5cm to 7cm, as see in Figures 6 – (c, d, and e), i.e., excellent detection and complete image can obtain when used a detector with radius 5cm and over. The lacks in the count rate of back scatter photons when using detector with radius less than 5cm due to the statistical counts in the procedure of simulation used in this work. For more illustration, summaries the count rate data of back scatter photons in the Table 1, which show the total number of back scatter photons at selected Compton angle (θ_{comp}) and the total number of scatter photons that detects or registers through a detector at different radius for each Fe and Fe_2O_3.



a) RD = 3cm



b) RD = 4cm

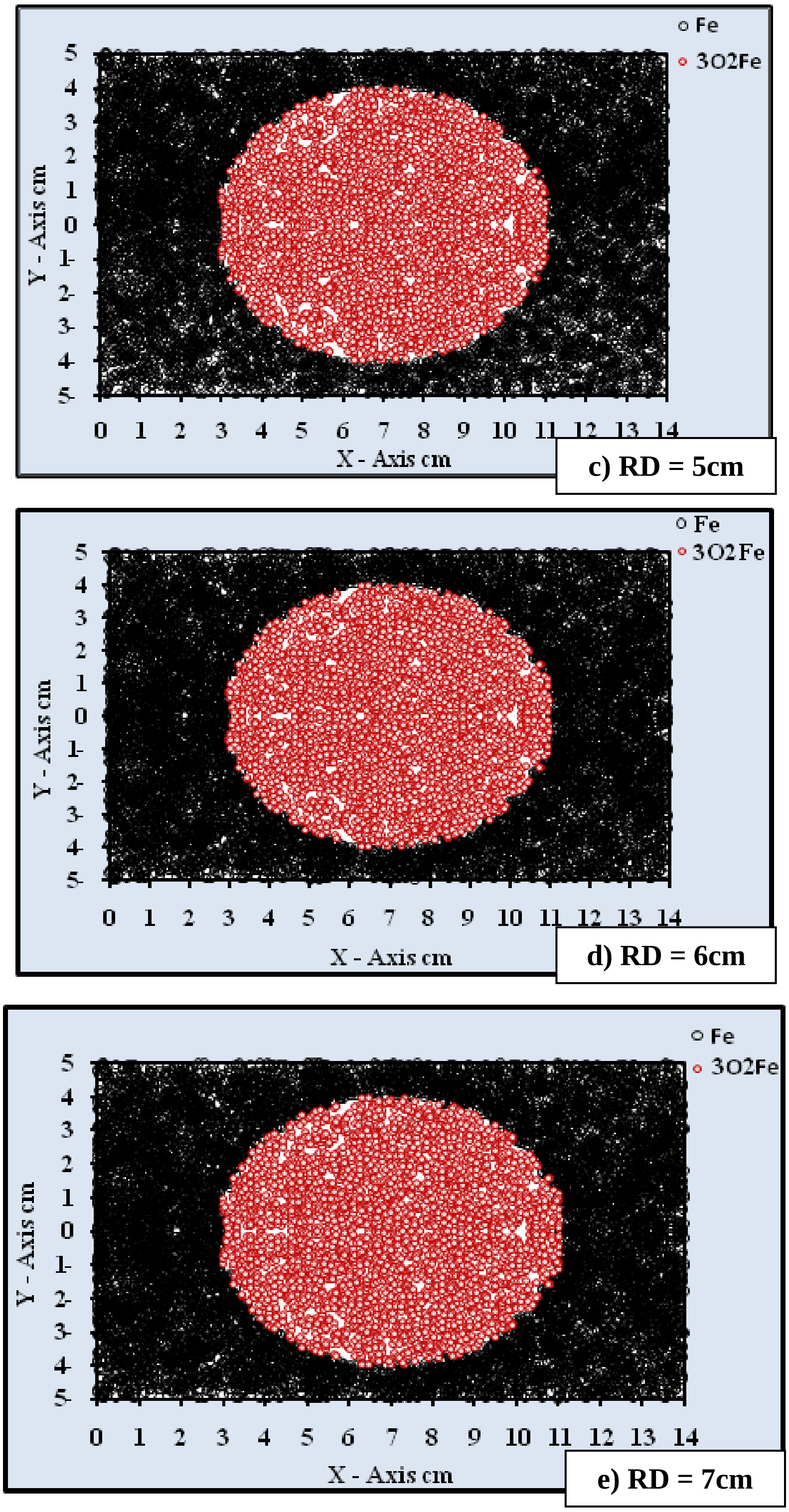


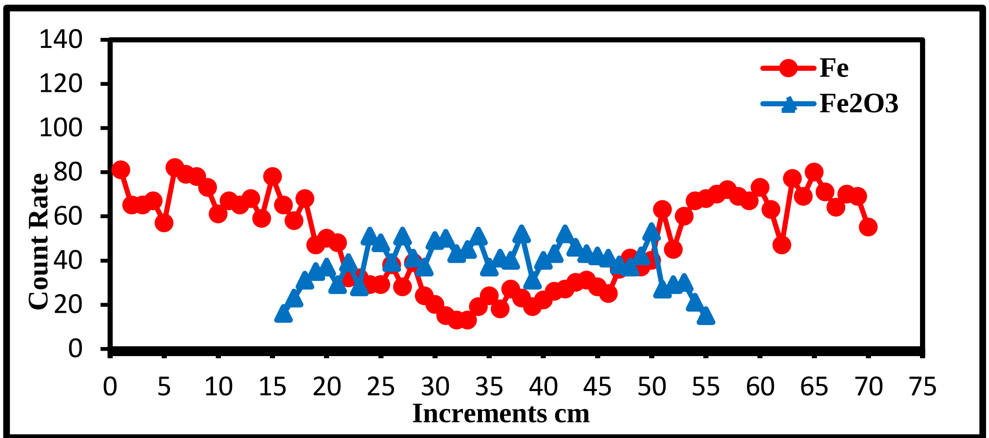
Figure (6): The 2D imaging simulation results for (MCBS) technique with different radius of detector; a) RD = 3cm, b) RD = 4cm, c) RD = 5cm, d) RD = 6cm, and e) RD = 7cm.

Table (1): Scattered and detected photons at different radius detector for Fe and Fe_2O_3 at θ_{Comp} average.

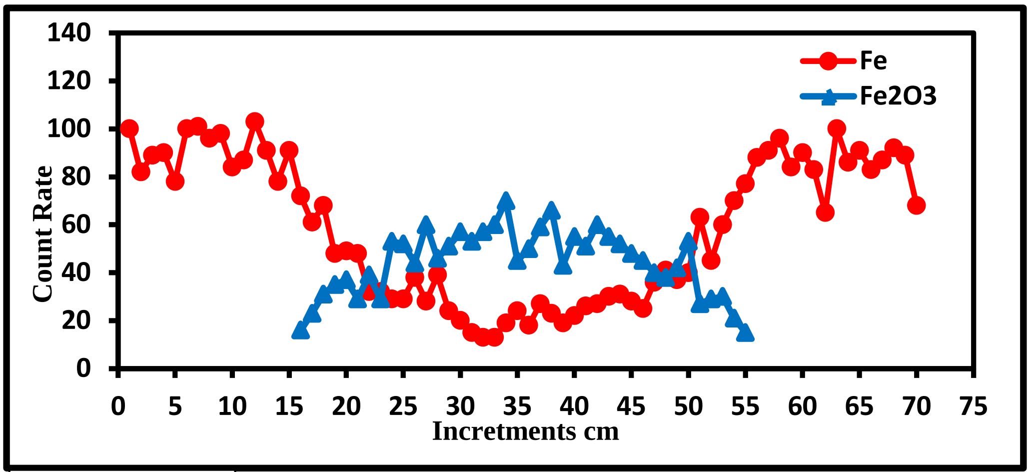
Detector radius cm	Scattered photons		Detected photons		Θ_{Comp} averge (min – max) degree	
	Fe	Fe_2O_3	Fe	Fe_2O_3	Fe	Fe_2O_3
3	473706	255831	3485	1543	133.28 – 135.59	133.75 – 135.66
4	474545	257089	4107	1750	133.28 – 135.59	133.91 – 135.66
5	474547	259746	4567	1766	133.28 – 135.59	133.91 – 135.66
6	474547	259746	4567	1766	133.28 – 135.59	133.91 – 135.66
7	474547	259746	4567	1766	133.28 – 135.59	133.91 – 135.66

Note: Supposed the total number of incident photons 20000 photon

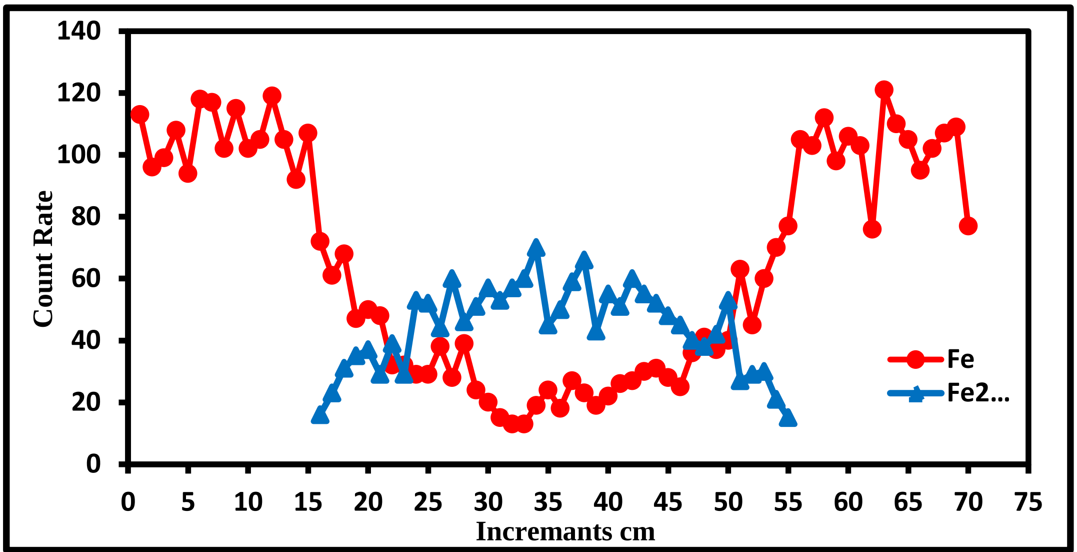
Figure 7 – (a, b, c, d and e) show the count rate behavior of backscattered photons in all sectors with 0.2cm increment for radius detector (RD= 3, 4, 5, 6 and 7), respectively, for Fe and Fe_2O_3. Therefore, when photons scanning the pure area (Fe) of the pipe surface, the count rate has high value, while it is decreases when scanning arrived to the corrosion area (Fe_2O_3) at the pipe surface; whereas photons scanning the corroded area (Fe_2O_3) the count rate will be increased because the ratio (or amount) of (Fe) will decrease in comparison with (Fe_2O_3) in the pipe surface, in addition to the affected of count rate by the attenuation coefficient of photons. Since the attenuation coefficient depends on the density of elements, i.e., if the material has a high density, the attenuation coefficient has small value, thus the count rate of scattered photon will be decrease, and vice versa. On this figures, red points and line is the count rate behavior from pure area (Fe) and blue points and line is from corrosion are (Fe_2O_3).



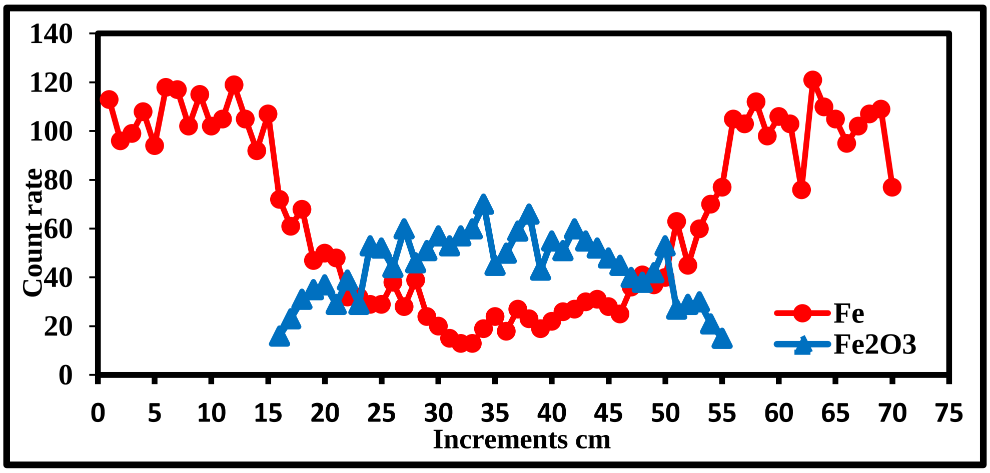
a) RD = 3 cm



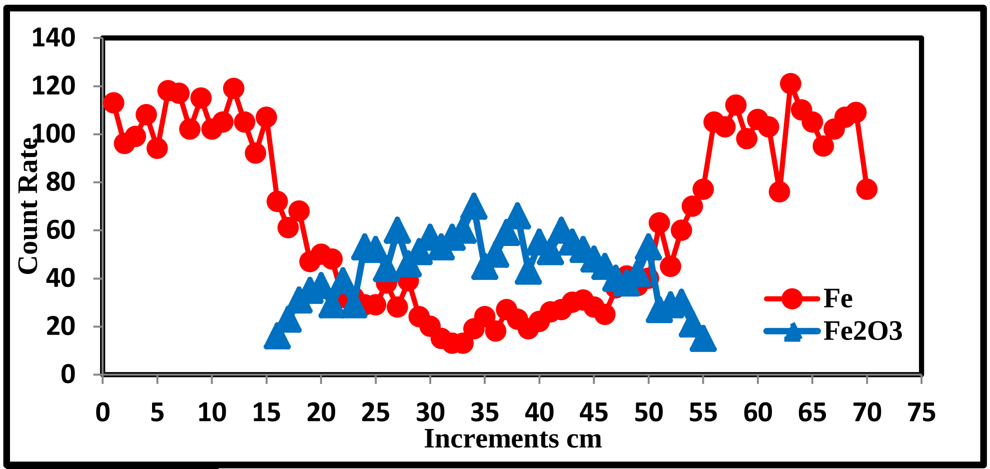
b) RD = 4 cm



c) RD = 5 cm



d) RD = 6 cm



e) RD = 7 cm

Figure(7): The count rate behavior of scattered photons from (MCBS) technique simulation for different detector radius:
a) RD = 3cm, b) RD = 4cm, c) RD = 5cm, d) RD = 6cm, e) RD = 7cm.

CONCLUSIONS

The results of the study described in this work clearly showed that (MCBS) technique simulation by gamma ray is very powerful technique for detecting and imaging the corrosion of steel pipes with or without insulator. Comparing with the most commonly used methods for the detection of corrosion, this technique can be used without any damage being caused to the inspection pipe. This makes it possible to follow the detection and imaging corrosion during work the pipe. Also, can be summarized the results that obtained from this simulation, as follows:

- The ratio of count rate for back scatter photons increase with increasing the detector radius from radius 3cm until 5cm, while it is fixed form radius 5cm and over.
- Generally, in the corrosion area the count rate for (Fe) is reduced compared to the non corrosion area, while (Fe2O3) count rate is increased in corrosion area.
- Choose detector with radius (6 cm) the best radius because it is a minimum radius that could used to give complete and excellent results.
- This reduction in the Fe count rate reach to about 33.3% of that for non corrosion area when using detector with radius (RD = 6) cm.

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