Issue : XVII, Vol . V
URA UNIVERSAL RESEARCH ANALYSIS
IMPACT FACTOR 5.35
ISSN 2229-4406
Sept. 2018 To Feb. 2019

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Study of Non-Destructive Testing Gamma Rays Interaction with Matter

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Research Paper - Physics

ABSTRACT

In today's rapidly growing world, the requirement of reliability is increasing day by day because new modern techniques (based upon advanced technology) are being introduced on a large scale. Non-destructive testing is the process used to examine the condition of an object without damaging it, so that the usefulness and integrity of object are not affected by investigation process. The term "non-destructive examination" (NDE) also refer to various evaluation, testing, monitoring, or inspection techniques that are performed to "examine" materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure and evaluate discontinuities, defects and other imperfections; to assess integrity, properties and composition; and to measure geometric characteristics [1]. In other words, Non-destructive testing (NDT) or Non-destructive Inspection (NDI), as the name imply, is technology of assessing soundness and acceptability of a material, component or structure without impairing its functional properties or 'Worth'. NDT techniques are used in practically *every engineering industry, space applications, nuclear establishments, power plants, chemical/fertilizer plants and medical field etc.*

Keywords : NDE, NDT, NDI, gamma ray etc,.

Introduction

To meet these requirements, NDE can be performed using different technical methods that rely on acoustic, optical, electric, magnetic, and electromagnetic or various other properties. Acoustic techniques encompass ultrasonic testing and passive monitoring of acoustic emission. Electric and magnetic methods involve eddy currents and magnetic flux leakage methods respectively, as well as techniques involving direct measurement of electric parameters like resistance, capacitance or inductance. Electromagnetic waves, including X-rays, gamma rays, microwaves, infra radiation, laser and natural light are also employed in NDE.

Although nuclear and atomic radiations require careful handling during their use (due to risk of exposure or contamination by potentially harmful radioactivity) even then gamma radiation based techniques are well acceptable in NDE as it is a non-intrusive, non-invasive and non-destructive examination method. Radiation can provide intrinsic properties that are not directly given by other methods, such as density and elemental composition. It can be used in harsh environments (high temperature, high pressure, corrosive, caustic, explosive, viscous media etc.), since radiation examination dose not require direct contact with inspected object. Radiation can be used with any type of medium regardless of its nature; i.e. the material can be in the form of a gas, liquid or solid, it can be conductive or insulating of heat or electricity; it can be ferromagnetic or non-magnetic, ceramic or metal, porous or impermeable, sealed or open, etc.

Need for Non-destructive testing

Material scientists and material engineers know that no material can be categorized as absolutely perfect (i.e. having zero defect). One can only minimize the amount of defect or may reduce defect size by proper selection of manufacturing processes or by improving production processes. As one has to live with the defects present in any material, component, product, system or plant without impairing their future usefulness. To meet this requirement, various NDT techniques are used [2].

Akin to medical field, where NDT is used as a diagnostic tool right from inception of a child (ultrasonogram of child in the womb) to old age, NDT today is an inseparable part in industrial world being used from cradle to tomb of a component i.e. right from raw material stage through fabrication, during service and also to determine remaining life of component. Also, it becomes necessary to characterize the defect and obtain quantitative information about its size, shape and location so that this could serve as an input to fracture mechanics calculations for predicting remaining life of component. This need was particularly strong in nuclear, defense and space industries. This led to emergence of Non Destructive Evaluation (NDE) as a new discipline. NDE refers to quantitative inspection in which the defect is not only detected, but also characterized with respect to its size, shape and orientation. Today, a number of research programs have evolved all over world in field of NDE [3].

Benefits of NDT

The main advantage of applying NDT for material inspection, during manufacturing process and for in-service inspection is that it:

1. ensures product quality, reliability and safety
2. controls manufacturing process to within specified tolerances
3. aids in optimum product design
4. ensures uniform quality levels
5. ensures customer satisfaction
6. predicts impending failures, thus preventing costly shutdowns and aids in plant life extension

A wide range of industries/professions use NDT methods. To name a few: Nuclear, Aerospace, Automotive, Chemical, Defence, Electronics, Electrical, Fabrication, Fertilizers, Food Processing, Marine, Medical, Metal & Non-metals,Petrochemical, Power, Security, etc. Indeed, progress of human civilization in many industrial activities would not have been possible without diagnostic NDT. The success of NDT depends on combination of Qualified Personnel, Calibrated Equipment, Documental practices and Standard Procedure and Codified Acceptance Criteria.

Efforts are currently being made by various industrial houses and research organizations to develop on-line monitoring NDT techniques i.e. NDT techniques which can inspect components/products etc. during manufacturing/service. On-line monitoring of machines, engines, turbines, railways etc. would avoid shut-downs for routine inspection and thus overhauls would become less frequent.

Types of NDT techniques

There are a number of NDT techniques which are used in various industries/ organizations for NDI. Some of these NDT techniques are for certain specific applications only to suit requirement of particular industry/organizations, whereas other NDT techniques are more broad based and may be used for varied applications. The common NDT techniques [1, 2 and 3] are discussed below in brief:

Gamma rays interaction with matter

The objective of present work is to study gamma ray techniques for non-destructive testing, so it becomes essential to have knowledge of various processes that occur during gamma rays interaction with matter. All interactions of radiation with matter occur at fundamental level of atoms or their more elementary constituents such as electrons and nuclei. There are a number of processes which can cause the gamma rays to be scattered or absorbed in a material. Fano [5] and Siegbahn [6] provided a systematic form of these interactions. Combining the kind of interaction with their effects produced in a material, there are twelve processes by which gamma rays can be absorbed or scattered. In intermediate energy range from 10 keV to 10 MeV, the most significant processes are:

1) Photoelectric effect
2) Compton scattering
3) Rayleigh scattering
4) Pair Production

Gamma ray interaction processes (like photoelectric effect, pair production, Compton effect, coherent scattering in the intermediate energy range are taken into consideration) can be categories on the basis of absorption and scattering as shown in Fig. 1.1.

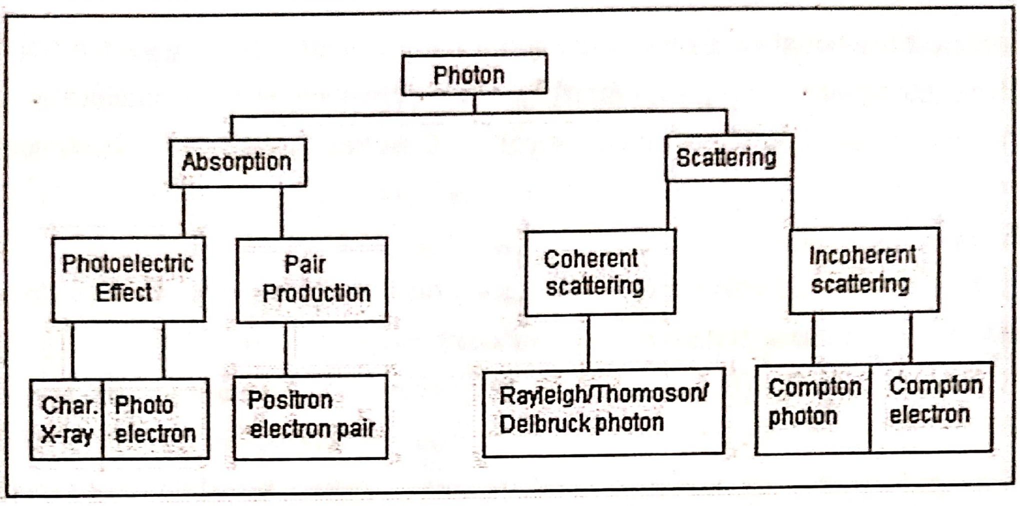

Fig.1.1: Gamma ray interaction in energy of nuclear domain.

The probability of occurrence of a particular type of process depends upon following factors:

i) energy of the incident photon

ii) scattering material

iii) scattering angle

iv) experimental conditions

The relative importance [7] of three major gamma ray interactions (Photoelectric effect, Compton scattering and Pair production) are shown in Fig. 1.2, which also indicates that for low-Z elements, Compton scattering dominates the other two over entire energy domain.

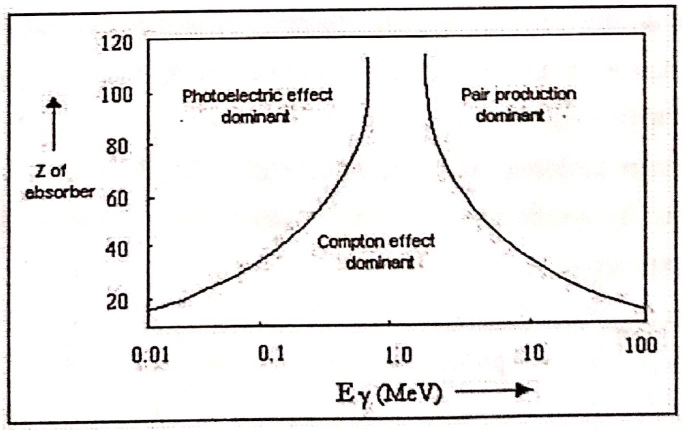

Fig.1.2: Relative importance of three major gamma ray interactions.

Photoelectric absorption, Compton scattering and Rayleigh scattering are the main processes to be taken into account for energy range of photons used in biomedical and industrial applications. To have more insight into these three processes, the details are given below:

Photoelectric effect

The photoelectric process (Fig.1.3-a) occurs when the incident photon (primarily of low energy) interacts with an inner orbital electron. When this

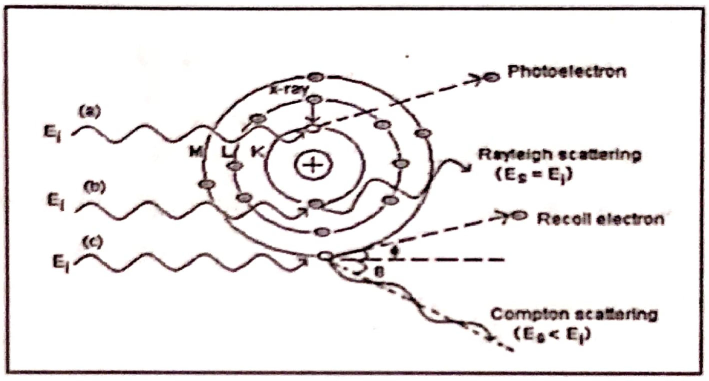

Fig.1.3: Summary of gamma ray interactions.

process occurs, energy of incident photon is transferred to orbital electron and the photon is completely absorbed. Since the electron is bound to atom, part of energy of photon is used for overcoming this binding energy. The balance appears as kinetic energy of ejected electron, from atom. This electron is also referred to as photoelectron. Since a vacancy now exists in one of the electron shells, an outer orbital electron will fall into that vacancy with a subsequent emission of characteristic X-rays. Photoelectric effect predominates for low incident energies (upto about 150 keV) and high atomic number materials. The atomic cross section, ?photoelectric, provides absolute probability of a photoelectric

interaction, and is given by

$$\sigma_{photoelectric} \propto \frac{Z^{4-5}}{h\nu^{7/2}} \quad (1.1)$$

The Z4-5 dependence means that for a given photon energy this process is more pronounced in high atomic number absorbers. Also its probability increases sharply with decrease in incident photon energy.

Comparison of transmission and scattering imaging for NDT

Although there has been considerable technical development over the last century since Roentgen's discovery of X-rays, the principle of transmission radiography has remained unchanged since then. This demonstrates the robustness of transmission radiography, a formidable opponent against which scatter imaging has to compete. The most significant points of comparison between the two in non-medical radiography are defect contrast, measurement geometry and system complexity needed for tomographic imaging. Details [15] for these points are elaborated below:

Backscatter measurement geometry

Conventional radiography is based on rectilinear propagation of X-rays/ gamma-rays from the radiation source to the detector where they are converted to a measurable signal. This is an example of an in-line imaging geometry, in which the object under investigation is inevitably located between source and detector. It is clear that such an imaging geometry, while being intuitively simple, can not be applied to objects of large spatial extent; as attenuation, radiations suffer in penetrating the object will prohibit measurement of transmitted radiation field. The possibility to place radiation source and detector on same side of object is without analogue in transmission radiography. It opens perspective for radiography of objects that would not otherwise be accessible to low energy transmission imaging.

scope of work

Non-destructive testing (NDT) are those evaluation methods in which the material under test is not destroyed or to say that future usefulness of material under test is not impaired. The ability of gamma rays to penetrate deep in matter makes it attractive for use in non-destructive testing applications. The objective of the present study is to examine the potential of using absorption and scattering of gamma rays to evaluate density variation in inspected objects.

Many investigators have already reported the theoretical as well as experimental work for tomographic (section-wise) non-destructive inspection of samples of medical and industrial interest. But the study reported here in present work is a fruitful extension to previous investigations (specially applying inverse matrix approach to obtain true spectra from observed pulse-height distribution in case of NaI(Tl) detector), so it is expected that experimental findings of present study will be quite useful to other investigators in improving their experimental design for field/clinical instruments.

To explore the use of gamma photons for medical diagnosis, especially for measurements of mandibular bone density and pulmonary edema, scattering techniques for 59.54 keV and 662 keV (Rayleigh to Compton scattered ratio and Compton scattering) have been reported in the present work as a non-destructive methods. Also, the applicability of gamma photons to process diagnosis in various samples of industrial interest has been studied, by image reconstruction with Matlab, as a non-destructive tomographic technique. Industrial interest applications involve investigations for pipeline conditions (wall thickness measurements, blockage detection and type of liquid flowing etc.) and flaw/inclusion locations for metal blocks/concrete materials. Apart from this investigations for landmine detection have also been performed with the help of gamma photon based scanning system. Moreover, an experimental technique (based on inverse matrix approach) for construction of response function, to obtain true photon spectrum from observed pulse-height distribution, for NaI(Tl) detector have been reported. Spectra obtained from NaI(Tl) detector for various studies have been corrected, for multiple scattering, with the help of this response matrix.

Scope of gamma ray non-destructive techniques is not limited to few applications only, but can be successfully employed for detection of presence or absence of rebars, voids etc. in structural engineering, agricultural, medical and industrial samples. Not only absorption but scattering techniques are also capable of distinguishing between rebars and air voids. Moreover, position and estimating the size of bars in reinforced concrete can be estimated by these methods. The density of some diseased parts of the human body, bones, lungs, tissue etc. can be evaluated by gamma ray scattering techniques. For any type of discontinuity (detection of flaws or presence of some inclusive materials) Compton scatter NDT can be employed for the detection. Images for any type of density variation can be obtained by using any appropriate software, which is one of the important features of non-destructive testing. Recent application of this technique is to detect the explosive in the baggage and land mines.

Conclusion

Several investigations have been made for 'tomographic non-destructive testing' of samples of medical and industrial interest by using various techniques as stated in section 1.3. This section includes survey of literature, for non-destructive inspection (NDI) of samples using X-rays or gamma rays as a radiation source.

Puumalainen et al. [17] presented a method based on measurement of intensity ratio of coherent to Compton scattered photons (in narrow beam geometry at scattering angles of 45 and 90) for in-vivo determination of stable iodine content of tissues. A 100 mCi 241Am radioactive source (emitting gamma photons of energy 59.54 keV) having active diameter of 7.8 mm was collimated by a cylindrical collimator of length 38 mm and diameter 7 mm. A Ge(Li) semiconductor detector with active diameter of 16 mm and energy resolution of about 400 eV at 60 keV was used to detect scattered radiations with a measuring time of 300 s. The sample solutions were prepared from KI in a plastic vial (volume 100 ml and diameter 47 mm) whose iodine contents varied between 0 and 10 mg/cm3. The authors concluded more suitability of this method for measurement of iodine content of tissues as compared to the X-ray fluorescence method.

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