SUMMARY

The objective of present study is to examine the potential of gamma rays to evaluate density variation in inspected objects using absorption and scattering techniques. Non-destructive testing (NDT) is the technique 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. In other words, Non-destructive testing techniques 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. Practically, NDT techniques are used in every engineering process, space applications, nuclear establishments, power plants, chemical/fertilizer plants and medical field etc.

Examining an object by destructive methods does not allow the use of testing object for future and it becomes more costly by destroying the sample. Moreover, inspection of large/thick size objects as a whole at once by destructive methods is inappropriate in many circumstances. Due to these limitations, part by part/sectional (tomographic) inspection of objects by non-destructive testing techniques needs to be used to examine various objects of medical and industrial interest. Also, the ability of gamma rays to penetrate deep in matter makes it attractive for use in non-destructive testing applications in large structures.

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 non-destructive evaluation (NDE) as it is a non-intrusive and non-invasive. Radiation can be used in harsh environments like high temperature, high pressure, corrosive, caustic, explosive, viscous media etc., since radiation examination dose
not require direct contact with the inspected object. Also, 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, conductive or insulating; ferromagnetic or non-magnetic, ceramic or metal, porous or impermeable, sealed or open, etc.

The work presented in the thesis consists of absorption/transmission and scattering tomographic gamma ray techniques for non-destructive testing of various samples. In first chapter, brief description of some common NDT techniques currently used in various industries/organizations for non-destructive inspection (NDI) is given. Applications and limitations of each technique are also mentioned. Three, gamma photon-matter interaction processes viz. Photoelectric effect, Compton scattering and Rayleigh scattering are described in detail. Comparison of transmission and scattering techniques depicts that scattering methods have advantages (provisions of variable geometry, access from one side, provide three dimensional information etc.) over transmission one. A survey of literature for non-destructive inspection of samples using X-rays or gamma rays as a radiation source is described in detail. This chapter ends with conclusion and scope of work for the present study.

In second chapter, a survey for the work already reported by various investigators, for the determination of response function of NaI(Tl) scintillation detector, is given. In the present study response function of NaI(Tl) scintillation gamma ray detector is obtained experimentally by taking into account the experimentally determined parameters such as peak-to-total ratio, intrinsic efficiency and full width at half the maximum (FWHM) height of the detector. Since FWHM varies as $E^{1/2}$ thus the photo-peaks will be of constant width on the $E^{1/2}$ scale, where $E$ is the incident source energy. The study demonstrates the inverse
matrix technique for constructing a 40 x 40 matrix, covering energy range from 0.625 keV to 1.0 MeV on a linear scale, with bin mesh (E)\(^{1/2}\) of 0.025 (MeV)\(^{1/2}\).

The experimentally constructed response matrix converts the observed pulse-height distribution of NaI(Tl) detector to a true photon energy spectrum by shifting all the events accumulated in the Compton continuum region (owing to the partial absorption of higher energy photons) to the full energy peak. This experimentally construction of response function, requires number of mono-energetic pulse-height distributions from different gamma ray sources as an input and it accounts the effects of materials surrounding the detector and attenuation of photons in the entrance window of detector. The inverse response matrix technique is quite useful in unscrambling of continuous gamma spectra with broad maxima.

In third chapter, principle for tomographic measurements, experimental arrangement, electronic set-up, calibration and efficiency of NaI(Tl) and High purity germanium (HPGe) detector and evaluation of self absorption correction factor for transmission and scattering geometry are discussed. The experimental arrangement used for the present study is divided into four parts; Radioactive sources (\(^{137}\)Cs & \(^{241}\)Am) and their housing, NaI(Tl) scintillation detector assembly, HPGe semiconductor detector and mechanical system for step wise motion of samples. The gamma ray spectrometers are calibrated using low activity standard gamma ray radioactive sources and a calibration line is drawn which shows the linearity of the spectrometer.

In fourth chapter, a tomographic scanner system, operating in a non-destructive and non-invasive way, is presented for absorption and scattering measurements for defect/anomaly detection in metal samples and concrete blocks. First, a metal sample for inspection is aluminium block (having void
diameter roughly 8 mm) of dimension 70 mm in length, 12 mm in breadth and 48 mm in height. Cylindrical rods of aluminium and iron are inserted one by one to fill the long cylindrical void in aluminium block and transmitted (or scattered) spectra are recorded for different inclusions. Another sample of iron block with dimensions of length 130 mm, breadth 16 mm and height 48 mm is also used for density variation inspection. Three long cylindrical voids, simulating flaw, of diameter 2 mm, 9 mm and 12 mm roughly at equal spacing from each other, has been drilled in a direction perpendicular to the direction of incident beam. The concrete block of dimension 180 mm in length, 80 mm in breadth and 70 mm in height having two cylindrical voids of 14 mm in diameter, is also used for investigation. As defects and inclusions directly effect the strength of material, so detection of these becomes essential for in-situation objects before they propagate to the point of causing failure/fracture.

The transmitted and Compton scattered intensity of 662 keV gamma photons, obtained by unfolding the experimental pulse-height distribution of NaI(Tl) scintillation detector, provides the desired information. Spectrum for different positions of various samples is recorded by moving the objects in horizontal direction by step wise motion with the help of a mechanical system. The measured values of transmitted (or Compton scattered) intensity at different scan positions are plotted as a function of position. The peak (or dip) position in this plot corresponds to the void/inclusion location in the sample for transmission (or scattered) measurements. Application of response function to the observed pulse height distribution results in increase in the intensity values and hence supports for the quality improvement of tomography. Although, scattering angle chosen in the present measurements is $110^\circ$, but similar results are expected at other
scattering angles, except the intensity values will get altered. The method is quite sensitive, for showing inclusion of medium atomic number (Z) material (iron) in low Z material (aluminium) and detecting a void of ~2 mm in size for iron block, to investigate the inhomogeneities in the object. Also, the grey scale images, reconstructed with MATLAB software package, are shown to visualise the presence of defects/inclusion in various reported investigations.

Moreover, a major inspection challenge facing the industry is how to examine insulated piping for blockage and corrosion, especially for corrosion under the insulation and internal erosion. This problem is especially troublesome for the petrochemical, refining, utility, mining and paper industries. The samples of cylindrical iron pipe with internal diameter varying from 2 mm to 20 mm are used for the study of pipe wall thickness. Also, investigations are undertaken by filling the iron pipe with different density liquids like petrol, diesel, multipurpose engine oil (API CF), water and glycerine, to examine the type of liquid flowing within pipe. Tomographic measurements are also performed to locate the position of pipeline in land soil and for detection of defect/fault in pipeline of length 140 mm and opening 22 mm having a cut/crack of width 1 mm up to the middle of pipe surrounded by insulation. This simulates the situation of pipe leakage under insulation. Hence the system can scan the defect easily under the insulation while pipe is in service, thus the measuring system can identify problem areas of a piping run, pinpointing where additional testing should take place. The technique can be employed to detect the thinning of pipe wall of the order of 1 mm due to corrosion, nature of liquid flowing in pipe having close values of density such that of petrol and diesel, crack/fault of 1 mm width under insulation and level indicator for containers having liquid etc. Moreover, results for landmine detection by using
gamma scattering technique have also been reported. Experimental phantom for explosive material is TNT simulant, prepared by mixing 17.3 gm graphite, 23.9 gm oxalic acid crystals and 58.8 gm cyanuric acid.

The absorption and scattering measurements for industrial applications are not limited to 662 keV gamma photons. But more portable densitometer systems can be designed using 59.54 keV gamma photons for inspection of thin sections of samples of low atomic number materials. The samples of aluminium pipe with different internal diameter/opening varying from 5 mm to 15 mm are used for this study and results are found to be quite satisfactory.

The study reported in present work for 662 keV gamma photons (specially applying inverse matrix approach to obtain true spectra from observed pulse-height distribution in case of NaI(Tl) detector) is a fruitful extension to previous investigations, so it is expected that the experimental findings of present work will be quite useful to other investigators in improving their experimental design for field instruments. Moreover, no experimental data is available for industrial applications by employing low energy 59.54 keV gamma photons.

In fifth chapter, objective is to explore the use of gamma photons as a non-destructive method for medical diagnosis purpose, especially for osteoporosis and pulmonary edema. The phantoms simulating mandibular bone and lung are prepared by mixing appropriate amount of distilled water with $\text{K}_2\text{HPO}_4$ and saw dust respectively. Rayleigh to Compton scattering intensity ratio technique is used for the measurements of mandibular bone density, by employing 59.54 keV gamma photons and an HPGe semiconductor detector for various scattering angles. The major advantages of this technique is that by taking intensity ratio of Rayleigh to Compton scattered photons, a number of parameters such as
absolute source strength, solid angles subtended by source and detector at the
target are eliminated in the expression of ratio technique, otherwise these
parameters introduce large amount of error in the final measured results. The
scattered intensity values are corrected for photo-peak efficiency of the detector,
absorption of gamma rays in air column present between phantom and detector,
and self-absorption in the phantom. Also, Compton scattering count rate and Wing
ratio (Compton profile ratio) techniques, for 662 keV energy, are examined for
detection of change in density of lung phantom.

The regression lines, obtained from experimental data of scattered intensity
as a function of phantom density, serve as calibration curves and provide the
density for unknown samples (lung and mandibular bone) of interest. These
results indicate that the technique has the potential for a measure of pathological
state like pulmonary edema and osteoporosis. The technique is quite sensitive for
small changes (limit ~0.023 gm/cm$^3$) in the density of lung phantom. The use of a
gamma emitting radioactive source offers the advantages over an X-ray system of
constant beam intensity; mono-energetic radiation, lower patient dose and
apparatus that can be made small and portable, and hence is quite useful in many
biomedical studies.

It is worthwhile to mention here that these applications of Compton
scattered technique are relatively new and many are still under development. The
present study provides the ability of Compton scattered technique to extract the
information about density variation from interior of sample. There is also need to
simulate the present experiment with some suitable Monte Carlo Simulation code
for better understanding of present work and to prototype the method in
field/clinical practice.