THE EFFECT OF NEUTRON IRRADIATION ON THE IMPEDANCE OF ASBESTOS

by

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DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has made in the text.

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ABSTRACT

The project was concerned with finding the effect of neutron irradiation on the impedance of asbestos. Asbestos is used as an insulator of electricity in homes and industries; and in places of high temperatures and ionising radiations. Asbestos papers called 'Terratex' and 'Novabestos' have been found to be most suitable for thermal and electrical insulation in the air-cooled transformers and reactors rated for operation at elevated temperatures and under conditions where the liquid cooled counterpart is unsuitable. Thus even though there is a ban on the manufacture and use of asbestos in some countries, this ban has not been completely enforced in many countries.

The impedance of samples of asbestos ceiling tiles were measured with an Impedance/Gain Phase Analyzer. The samples were then irradiated with a constant neutron flux to different time intervals using the Miniature Neutron Source Reactor (MNSR) at Kwabenya, Accra. A control sample X was not irradiated. A second impedance measurement of the samples was made. Before irradiation the mean impedance of the asbestos samples was μ = 295.91kΩ, at a standard deviation of σ = 2.86kΩ. After irradiated with a mean neutron flux density of 11.25×10^{11}ncm^{-2} for an average time interval of 2.25 hours, the impedance of the samples was found to be lowered to a mean impedance of $\bar{X}$ = 281.22kΩ, at a standard deviation of s_X = 5.42kΩ. A difference in sample means of about 14.69kΩ. At α = 0.05 and d.f. = 9, the critical value of t was -1.83 The calculated value was -8.58. The null hypothesis was rejected since -8.58< -1.83 lies in the critical region. Thus at a significance level of α = 0.05 (i.e. 95% confidence interval), the t test indicates that the difference in the sample means was significant. Thus, by irradiating an asbestos sample with neutrons the impedance will be lowered.

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DEDICATION

This work is dedicated to my daughter Elisheba Yinbemi Tindan.

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CHAPTER ONE: INTRODUCTION

1.1. Background of the Study

There are all kinds of radiation emitted into the earth. These emissions are either by natural or artificial means. Scientists have been aware of both the beneficial and destructive potential of radiation (especially, ionising radiation). Radiation can be put into beneficial uses in the fields of medicine, industry, agriculture and radioactive dating. Gamma rays from ^{60}Co source are used in the treatment of cancer and in the sterilization of medical equipment. Iodine 131 is used as tracers by doctors to see how well the thyroid glands of patients are working. X rays are used to examine bones and foreign objects in the body. Radioactive tracers are used to detect leaks in underground pipes. A beta particle source may be used to automatically control the thickness of paper, plastic and metal sheets being rolled in a mill. Alpha particle source is used in smoke detectors.

Gamma rays are used to examine castings which are too massive to be dealt with by the less powerful X rays. X rays are used in crystallography to study the structure of crystals. Thermal neutrons are used in the nuclear reactor to cause fission to generate energy which is used in the production of electricity.

Tracers (radioactive phosphorus) are used to show how well plants are absorbing phosphorus. Gamma rays are used to sterilize some male insects and so reduce the insect population-the Sterile Insect Technique (SIT). Gamma rays are also used to sterilize plant and animal products to preserve them for export-food preservation.

Radioactive Dating: Radioactive dating is used in carbon dating to determine the age of fossilized materials.

Ionising radiation, despite its many beneficial applications, is extremely dangerous. Any exposure to ionising radiations increases ones risk of radiation hazard. Heavy doses cause radiation sickness and even death. The structure of living cells can be altered by radiation, possibly causing genetic damage [1]. Besides, interaction of radiation with matter can change its structure or composition thereby changing its physical or chemical properties.

By using the knowledge gained over the years and by employing effective methods to limit or eliminate the hazards, humans can exercise greater control over the use of radiant energy. Radiologic Technologists and Radiologists educated in the safe operation of imaging equipment can follow practices, use protective devices, and select technical exposure factors that significantly reduce radiation exposure to patients and themselves.

1.2 Statement of the Problem

As mentioned earlier, radiation issues are serious issues that need not be handled lightly. In living cells ionising radiation can disrupt chemical bonds in essential macromolecules such as DNA, and produce molecular fragments, which are free polyatomic ions that can interfere with enzyme and other more essential cell functions.

In Table 1.1 the estimated results of various levels of acute radiation exposure are compared.

Table 1.1: Approximate Single Dose, whole Body Effects to Radiation Exposure.[2]

Radiation Level (Sv)	Comments
0.0013	Average annual exposure to natural background radiation.
0.005	Upper limit to annual exposure to general public.
0.25	Threshold for observable effects such as blood count changes.
1.00	Fatigue and other symptoms of radiation sickness.
2.00	Definite radiation sickness, bone marrow damage, possibility of developing leukemia.
5.00	Lethal dose for 50 percent of individuals.
10.00	Lethal dose for all.

Even though there is a lot of research and information on the effect of radiation on tissue matter, there is not as much research and information on the effect of radiation on non-tissue matter. Non-tissue materials like dead organic matter, plastics and inorganic materials like the stones and metals are all in the environment and are equally exposed to all radiations including neutrons that are released into the environment. It is common experience that newly built houses, purportedly built to standard specifications crumble to the ground. Houses, markets, stores and factories are seen suddenly guttered by fires for reasons hardly convincing. Several reasons could always be proposed for these problems, like poor re-enforcement, electrical fault, lightning and others. But it could also be because some properties of the materials like hardness, elasticity, impedance, thermal conductivity and so on have been altered as a result of exposure to radiation in the atmosphere.

The problem is that many physical structures and the environment are experiencing various kinds of damages. Many times the reasons often provided for these damages are not convincing enough. At the same time there is normally not enough information to show whether the damage could not have been caused by exposure to some kind of radiation that have been released into the atmosphere. The sun releases all kinds of radiations including neutrons through thermonuclear fusion as shown below.

$$
\begin{aligned}
&{}^{3}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n \\
&{}^{3}_{1}H + {}^{4}_{2}He \longrightarrow {}^{6}_{3}Li + {}^{1}_{0}n \\
&{}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n
\end{aligned}
$$

Cosmic radiation interacting with the earth's atmosphere continuously generates neutrons that can be detected at the surface. These released neutrons also interact with the materials they come into contact with on their way, and so can change their properties. Nuclear fission reactors naturally produce free neutrons. Whether thermal, intermediate or high energy neutrons, they can interact with and affect whatever surface they come into contact with.

With reference to asbestos, it has been noticed that asbestos has so many uses in industry and in construction. It is used in many products which include low density insulation board and ceiling tiles , Asbestos-cement sheets and pipes for construction, casing for water and electrical/telecommunication services , and thermal and chemical insulation (i.e., fire rated doors, limpet spray, lagging and gaskets).

The demand for reliability in electrical equipment under severe conditions of temperature and weather has necessitated the development of papers having insulating qualities and thermal stabilities far above those found in rope and wood-pulp products. Two approaches to the solution of the problem have been investigated; the one involving the beneficiation and modification of naturally occurring paper-forming inorganic materials, and the other, the preparation, synthetically, of fine inorganic fibres suitable for paper making. In the first category, asbestos, bentonite, and mica are found, while glass fibre and silica fibre occur in the latter. Recognizing the deficiency of the films, Walter[2] developed the bentonite-modified asbestos papers called 'Terratex' Modifications of these types, including 'Novabestos', have been disclosed. The asbestos papers found their immediate use in the air-cooled transformers and reactors rated for operation at elevated temperatures and under conditions where the liquid cooled counterpart is unsuitable.[3]

Thus even though there is a ban on the manufacture and use of asbestos in some countries, this ban has not been completely enforced in many countries including U.S.A. Countries like India and China have continued widespread use of asbestos. The most common is corrugated asbestos-cement sheets or A/C Sheets for roofing and for side walls. Millions of homes, factories, schools or sheds and shelters continue to use asbestos. Eternit Everest, Hyderabad Industries and RamCo are some of the major asbestos products manufacturers in India.[4] There have been no significant change in production and use of A/C Sheets in developing countries following the widespread restrictions in developed nations.

Despite these varying uses of asbestos, and the possible uses to which it could be put to in the future, there is not enough research, or rather, there is a lowering of research into the properties of asbestos, and how the electrical impedance of asbestos is affected by neutron irradiation. This is the problem that this project seeks to address.

1.3 Purpose and Significance of the Study

The perennial energy crisis in the country has prompted many people to begin to speculate whether the adoption of nuclear energy will not solve it. Nuclear energy employs radioactive elements which when they decay release radiations into the environment. Besides, nuclear reactors employ thermal neutrons to cause chain fission reaction which lead to the release of the energy. These thermal neutrons can leak due to a fault in the reactor. When this happens the neutrons are released into the environment and irradiate any material on their path.

The purpose of the study is to find out how the neutron irradiation affects the electrical impedance of the non-tissue materials (specifically asbestos) in the environment that are being irradiated. Will the impedance be lowered or raised. Asbestos is of interest because it is still very much in use domestically and industrially (including nuclear stations) for electrical and thermal insulation. The study on the effect neutron irradiation have on the electrical impedance of asbestos will determine how long asbestos will continue to serve the purpose of electrical insulation in situations where they come into contact with neutrons and interact with them.

The significance of the study is in the following areas.

i. It will provide new data and information for scientific reference. From the literature reviewed there is not much information on the effect of neutron irradiation on the electrical impedance of asbestos.

ii. It will provide necessary information to the Environmental Protection Agency (EPA) to know what precautionary measures to take especially in situations where there is possible neutron leakage and where asbestos products are still in use to check electrical fires and similar hazards.

iii. It will provide information that will help in assessing how long asbestos can be used as insulation for electricity in a particular environment.

iv. It might also open up other ways to which asbestos could be used in areas that will limit humans from getting too much in contact with it to minimize its health risk.

v. It will afford policy makers the necessary information to make proper assessment as to the degree to which the ban on the production and use of asbestos products should be enforced.

The significance of the study is not exhausted by this list. Many more could be added to it.

1.4 Research Question

In line with the objective of the study, the question answered by the study is basically this:

What is the effect of neutron irradiation on the electrical impedance of asbestos?

That is to say, will irradiating the asbestos with neutrons increase its electrical impedance, lower it or will not change it.

1.5 Research Hypothesis

Neutrons issuing from a reactor have their kinetic energies distributed in much the same way as those of gas molecules in thermal equilibrium; i.e., they follow the Maxwell distribution law. The largest fraction of these so-called 'thermal neutrons' has energy equal to $k_B T$, where k_B is Boltzmann's constant and T the absolute temperature.

Because of their charge neutrality, neutrons are not subject to Coulomb forces. Since neutrons interact very weakly with electrons, matter appears quite 'open' to free neutrons. In general, it is found that the rate of neutron-induced reactions increases as the neutron kinetic energy decreases. Free neutrons undergo beta decay with a mean lifetime of about 10 minutes. On the other hand, neutrons travelling through matter are absorbed by nuclei before they decay.

A fast neutron (energy greater than about 1 MeV) travelling through matter undergoes many scattering events with the nuclei. In each such event, the neutron gives up some of its kinetic energy to a nucleus. The neutron continues to undergo collisions until its energy is of the order of the thermal energy k_BT. A neutron having this amount of energy is called a thermal neutron. At this low energy, there is a high probability that the neutron will be captured by a nucleus, an event that is accompanied by the emission of a gamma ray. The generalised equation for neutron capture can be written as

$$ {}_0^1n + {}_Z^AX \rightarrow {}^{A+1}_{Z}X + \gamma. $$

Once the neutron is captured, the nucleus ${}^{A+1}_{Z}X$ is in the excited state for a very short time before it undergoes radioactive decay. Also, the product nucleus ${}^{A+1}_{Z}X$ is usually radioactive and decay by beta emission; i.e.,

$$ {}^{A+1}_{Z}X \longrightarrow {}^{A+1}_{Z+1}Y + {}^{0}_{-1}e. $$

Amosite (brown asbestos), is a trade name for the amphiboles belonging to the Cummingtonite - Grunerite solid solution series, commonly from Africa, named as an acronym from Asbestos Mines of South Africa.[5] One formula given for amosite is

$Fe_7Si_8O_{22}(OH)_2$. It is found most frequently as a fire retardant in thermal insulation products and ceiling tiles. This is the type of asbestos that was used for the project. The hydrogen (H), being light may undergo elastic collisions with the neutrons. These collisions result mainly in slowing down the neutrons. But iron (Fe), silicon (Si) and oxygen (O) can result in fissionable interaction with the neutrons, resulting in gamma and beta emission.

Beta ($_{-1}^{0}e$) emission into the system indicates that free electrons will be released into the system or into the bulk of the material. The introduction of free electrons into a material will increase the conductivity, and for that matter decrease the impedance of the material. Hence, the following hypothesis was made.

Alternate Hypothesis, H_1: 'Neutron irradiation will decrease the electrical impedance of asbestos'.

That is, $\mu_A < \mu_B$.

Null Hypothesis, H_0: 'Neutron irradiation will not decrease the electrical impedance of asbestos'.

That is, $\mu_A \geq \mu_B$.

Where, μ_A and μ_B are the mean impedances after irradiation and before irradiation respectively.

1.6 Limitations and Delimitations of the Study

One would have wished to do a more thorough study on asbestos to include the effect of other radiations in the atmosphere like gamma, beta, alpha, X-ray and even proton irradiation on its properties. Besides, other properties of asbestos like its thermal conductivity, modulus of elasticity, specific heat capacity and ductility could have been investigated. But these are not possible because of the limitations encountered. The limitations include the shortness of the time frame within which the project was to be completed, financial constraint and unavailability of the necessary equipment. This project was to be completed within eight months. Money is needed to buy the necessary materials, pay rent for the use of other facilities and in preparing the samples. The sources of the various radiations and the machines that can take the various measurements are not easily within reach.

These constraints will obviously delimit the scope of applicability of the findings of the project. It is not expected that the findings of the project should be applied to all ceramics. Its applicability should be limited to asbestos only. The study was on the effect of neutron irradiation and so it should not be interpreted to imply that other radiations will yield the same effect on the impedance of asbestos.

However, even though amosite (brown asbestos) was used in the study, the findings could apply for crocidolite (blue asbestos) and chrysotile (white asbestos). But, this must be done cautiously.

1.7 Operational Definition of Terms

Ionising radiation: Radiation that produces positively and negatively charged particles (ions) when passing through matter.

Radiant energy: Electromagnetic and particle radiations usually released into the atmosphere or some other medium.

Tracers: Radioactive isotopes used to monitor the progress of an element or its compounds through a living organism or process pathway (such as in the soil or through a gas pipe) by providing non-radioactive isotopes of the same element with a radioactive ‘tag’.

Thermal neutron: A relatively slow-moving neutron that possesses less than or equal to 1 MeV of kinetic energy and is capable of bringing about nuclear fission. Typically, these are neutrons whose kinetic energy has been significantly degraded as a result of multiple energy loss collisions.

Irradiation: The act of exposing somebody or something to radiation or streams of particles.

Impedance: Opposition to flow of alternating current; the opposition in an electrical circuit to the flow of alternating current, consisting of resistance and reactance. Symbol Z.

Sievert: Effective dose of different types of radiation that produce equal biological effects. One gray of alpha radiation, for example, will have a greater effect than one gray of beta radiation. But regardless of the type of radiation, one sievert (Sv) of radiation produces the same biological effect. Radiation effects are therefore expressed in a unit called the sievert (Sv). One sievert equals one joule of energy absorbed per kilogram of tissue. Smaller quantities are expressed in 'millisievert' (one thousandth) or 'microsievert' (one millionth) of a sievert.

Average Impedance after Irradiation (AIAI): The mean of the impedance of each pair of asbestos samples after they were irradiated with neutrons.

Average Impedance before Irradiation (AIBI): The mean of the impedance of each pair of asbestos samples before they were irradiated with neutrons.

Neutron Flux Density (NFD): A measure of the intensity of neutron radiation in neutrons per centimetre square per second. It is the number of neutrons passing through 1 square centimetre of a given target in 1 second.

CHAPTER TWO: LITERATURE REVIEW

2.1 Background

Life, if not impossible will be odd without radiations. Yet the wrong application of radiation or a disproportionate exposure to radiation can lead to deformation of matter and an eventual extinction of life. Issues concerning radiation are very crucial and many environmentalists, physicians, physicists and government agents show great concern to radiation issues.

Information on the effects of radiation on the properties of non-tissue matter is however not very available. More scarce is relevant literature on the effect of radiation on the impedance matter. The litigations surrounding the production and use of asbestos have made it less attractive for researchers to work with [6]. This goes further to affect the amount of relevant literature on the topic under study.

2.2 Radiation

Radiation is energy travelling through space. Sunshine is one of the most familiar forms of radiation. It delivers light, heat and suntans. Exposure to it by man is controlled with sunglasses, shade, hats, clothes, lotion and sunscreen. Sunshine consists of radiation in a range of wavelengths from long-wavelength infra-red to short-wavelength ultraviolet, which creates the hazard. Beyond ultraviolet radiation there are higher energy kinds of radiation which are used in medicine and which the body receives in low doses from space, from the air, and from the earth. Collectively these kinds of radiation can be referred to as ionising radiation. Ionising radiation comes from the atomic nucleus. It occurs in two forms - rays and particles, at the high frequency end of the energy spectrum. Ionising radiation produces electrically-charged particles called ions in the materials it strikes. This process is called ionisation. Ionising radiation has the ability to affect the large chemical molecules of which all matter are made and so cause changes in their properties. It can cause damage to matter, particularly living tissue. At high levels it is therefore dangerous; so it is necessary to control exposure to it.

Ionising radiation is produced by radioactive decay, nuclear fission and nuclear fusion, by extremely hot objects (e.g. the hot sun and other stars), x-ray tubes and by particle accelerators that may produce fast electrons or protons or bremsstrahlung or synchrotron radiation.

2.2.1 Types of Radiation

2.2.1.1 Infrared Radiation (IR)

This is radiation emitted or reflected in the infrared portion of the electromagnetic spectrum. The name means ‘below red’ (from Latin,’ infra’, meaning, ‘below’); red being the colour of the longest wavelengths of visible light. Infrared (IR) light has a longer wavelength than that of red light [6]. Infrared radiation has wavelengths between about 750 nm and 1 mm, spanning five orders of magnitude.

At the atomic level, infrared energy elicits vibrational modes in a molecule through a change in the dipole moment, making it a useful frequency range for study of these energy states. Infrared spectroscopy examines absorption and transmission of photons in the infrared energy range, based on their frequency and intensity.[7]

2.2.1.2 Visible Light

The visible spectrum (or sometimes called the optical spectrum) is the portion of the electromagnetic spectrum that is visible to the human eye. Electromagnetic radiation in this range of wavelengths is called visible light or simply light. A typical human eye will respond to wavelengths in air from about 380 to 750 nm.[7] The corresponding wavelengths in water and other media are reduced by a factor equal to the refractive index. In terms of frequency, this corresponds to a band in the vicinity of 400-790 terahertz. A light adapted eye generally has its maximum sensitivity at around 555 nm (540 THz), in the green region of the optical spectrum. The spectrum does not, however, contain all the colours that the human eyes and brain can distinguish. Brown, pink, and magenta are absent, for example, because they need a mix of multiple wavelengths, preferably shades of red.[7]

Visible light waves are the only electromagnetic waves we can see. We see these waves as the colours of the rainbow (Figure 2.1). Each colour has a different wavelength. Red has the longest wavelength and violet has the shortest wavelength. When all the waves are seen together, they make white light. When white light shines through a prism, the white light is broken apart into the colours of the visible light spectrum (Figure 2.2). Water vapour in the atmosphere can also break apart wavelengths creating a rainbow. Each colour in a rainbow corresponds to a different wavelength of electromagnetic spectrum.

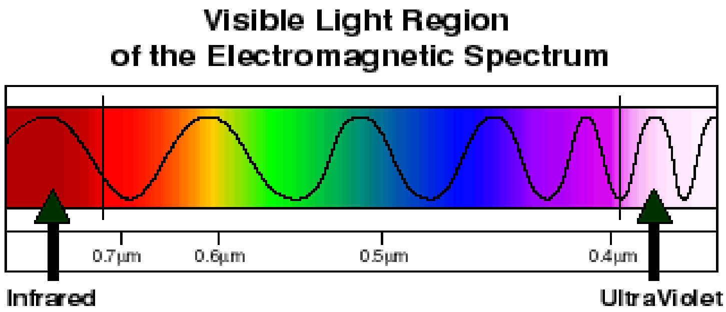

Figure 2.1: The Visible Light Region.

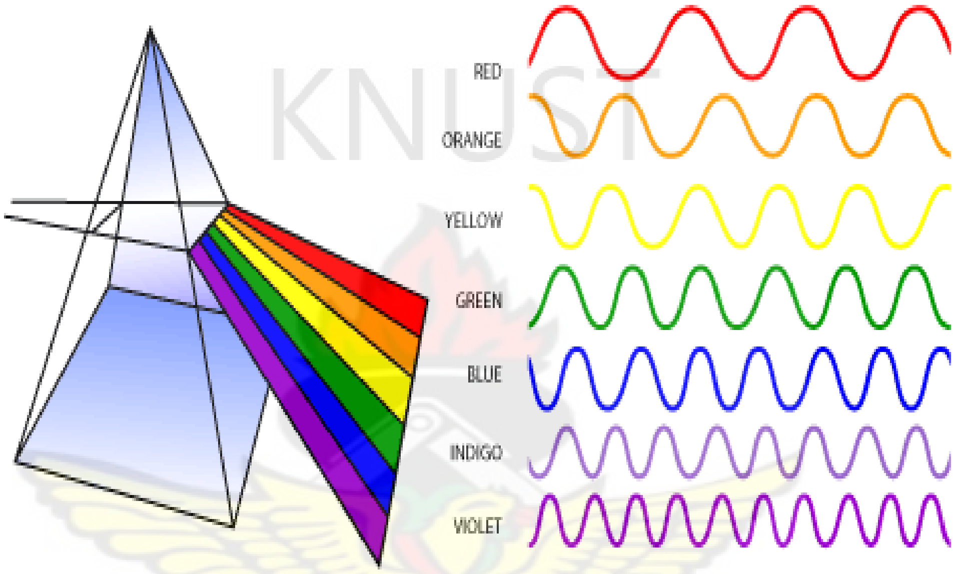

Figure 2.2: The Separate Wavelengths of Visible Light.

2.2.1.3 Ultraviolet Radiation (UV)

The name UV means 'beyond violet' (from Latin 'ultra', 'beyond'); violet being the colour of the shortest wavelengths of visible light. UV light has a shorter wavelength than that of violet light. The part of the electromagnetic spectrum which ultraviolet light covers can be further subdivided in several different overlapping ways.[8]

In photolithography and in laser technology, the term deep ultraviolet or DUV refers to wavelengths below 300 nm. 'Vacuum UV' is so named because it is absorbed strongly by air and is used in vacuums.[9]

Table 2.1: Subtypes of Ultraviolet Radiation.[10]

Name	Abbreviation	Wavelength range in nanometers /nm	Energy per photon/eV
Near	NUV	400 - 200	3.10 - 6.20
UVA, long wave, or black light		400 - 320	3.10 - 3.87
UVB or medium wave		320 - 280	3.87 - 4.43
UVC, short wave, or germicidal		Below 280	4.43 - 6.20
Far or vacuum UV	FUV, VUV	200 - 10	6.20 - 124
Extreme or deep UV	EUV, DUV	31 - 1	40 - 1240

2.2.1.4 X – Radiation

X-rays are a type of electromagnetic radiation with wavelengths of around 10^{-10} meters. When medical X-rays are being produced, a thin metallic sheet is placed between the emitter and the target, effectively filtering out the lower energy (soft) X-rays. This is often placed close to the window of the X-ray tube. The resultant X-ray is said to be hard. Soft X-rays overlap the range of extreme ultraviolet. The frequency of hard X-rays is higher than that of soft X-rays, and the wavelength is shorter. Hard X-rays overlap the range of long-wavelength (lower energy) gamma rays, however the distinction between the two terms depends on the source of the radiation, not its wavelength; X-ray photons are generated by energetic electron processes, gamma rays by transitions within atomic nuclei.

The basic production of X-rays is by accelerating electrons in order to collide with a metal target. (In medical applications, this is usually tungsten or a more crack resistant alloy of rhenium (5%) and tungsten (95%), but sometimes molybdenum for more specialized applications, such as when soft X-rays are needed as in mammography. In crystallography, a copper target is most common, with cobalt often being used when fluorescence from iron content in the sample might otherwise present a problem). Here the electrons suddenly decelerate upon colliding with the metal target and if enough energy is contained within the electron it is able to knock out an electron from the inner shell of the metal atom and as a result electrons from higher energy levels then fill up the vacancy and X-ray photons are emitted. This process is extremely inefficient (about 0.1% efficiency) and thus to produce reasonable flux of X-rays plenty of energy has to be wasted into heat which has to be removed.

X-rays can detect cancer, cysts, and tumours. Due to their short wavelength, in medical applications X-rays act more like a particle than a wave. This is in contrast to their application in crystallography, where their wave-like nature is most important. Nowadays, for many (non-medical) applications, X-ray production is achieved by synchrotrons.

To take an X-ray of the bones, no iodisation is required. Short X-ray pulses are shot through a body at first. Next, the bones absorb the most waves because they are more dense and contain Ca which absorbs stronger than the carbon, oxygen, and nitrogen atoms of soft tissue (due to more electrons in Ca atom).[11]

2.2.1.5 Gamma Radiation

Gamma rays (denoted as γ) are a form of electromagnetic radiation or light emission of frequencies produced by sub-atomic particle interactions, such as electron-positron annihilation or radioactive decay. Gamma rays are generally characterized as electromagnetic radiation having the highest frequency and energy, and also the shortest wavelength, within the electromagnetic spectrum; that is, high energy photons. Due to their high energy content, they can cause serious damage when absorbed by living cells.

2.2.1.6 Beta Particles

Beta particles are high-energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei such as potassium-40. The beta particles emitted are a form of ionising radiation also known as beta rays. The production of beta particles is termed beta decay. They are designated by the Greek letter beta (β). There are two forms of beta decay, β^- and β^+, which respectively give rise to the electron and the positron.

An unstable atomic nucleus with an excess of neutrons may undergo β^- decay, where a neutron is converted into a proton, an electron and an electron-type antineutrino (the antiparticle of the neutrino):

$$n \rightarrow p + e^- + \bar{\nu}_e.$$

This process is mediated by the weak interaction. The neutron turns into a proton through the emission of a virtual W^- boson. At the quark level, W^- emission turns a down-type quark into an up-type quark, turning a neutron (one up quark and two down quarks) into a proton (two up quarks and one down quark). The virtual W^- boson then decays into an electron and an antineutrino.

Beta decay commonly occurs among the neutron-rich fission by-products produced in nuclear reactors. Free neutrons also decay via this process. This is the source of the copious amount of electron antineutrinos produced by fission reactors. Unstable atomic nuclei with an excess of protons may undergo β^+ decay, also called inverse beta decay, where a proton is converted into a neutron, a positron and an electron-type neutrino:

$$p \rightarrow n + e^+ + v_e \ .$$

Beta plus decay can only happen inside nuclei when the absolute value of the binding energy of the daughter nucleus is higher than that of the parent nucleus. Inverse beta decay is one of the steps in nuclear fusion processes that produce energy inside stars.

2.2.1.7 Alpha Particles

Alpha particles (named after and denoted by the first letter in the Greek alphabet, α) consist of two protons and two neutrons bound together into a particle identical to a helium nucleus; hence, it can be written as He^{2+} or ${}^{4}_{2}He$. They are a highly ionising form of particle radiation, and have low penetration. The alpha particle mass is 6.644656×10^{-27} kg, which is equivalent to the energy of 3.72738 GeV. The charge of an alpha particle is equal to +2e, where e is the magnitude of charge on an electron, e = $1.602176462 \times 10^{-19}$C.

Alpha particles are emitted by radioactive nuclei such as uranium or radium in a process known as alpha decay. This sometimes leaves the nucleus in an excited state, with the emission of a gamma ray removing the excess energy. In contrast to beta decay, alpha decay is mediated by the strong nuclear force. Classically, alpha particles do not have enough energy to escape the potential of the nucleus. However, the quantum tunnelling effect allows them to escape.

When an alpha particle is emitted, the atomic mass of an element goes down by roughly 4.0015 u, due to the loss of 2 neutrons and 2 protons (NB: u = 1.66054 x 10^{-27} kg). The atomic number of the atom goes down by 2, as a result of the loss of 2 protons; the atom becomes a new element. An example of this is when radium becomes radon gas due to alpha decay: ${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$.

The energy of alpha particles varies, with higher energy alpha particles being emitted from larger nuclei, but most alpha particles have energies of between 3 and 7 MeV. This is a substantial amount of energy for a single particle, but their high mass means alpha particles have a lower speed (with a typical kinetic energy of 5 MeV the speed is 15,000 km/s) than any other common type of radiation (β particles, γ rays, neutrons, etc). Because of their charge and large mass, alpha particles are easily absorbed by materials and can travel only a few centimetres in air. They can be absorbed by tissue paper or the outer layers of human skin (about 40 micrometers, equivalent to a few cells deep) and so are not generally dangerous to life unless the source is ingested or inhaled.[12] Because of this high mass and strong absorption, however, if alpha radiation does enter the body (most often because radioactive material has been inhaled or ingested), it is the most destructive form of ionising radiation. It is the most strongly ionising; and with large enough doses can cause any or all of the symptoms of radiation poisoning. It is estimated that chromosome damage from alpha particles is about 100 times greater than that caused by an equivalent amount of other radiation.

The alpha emitter polonium-210 is suspected of playing a role in lung and bladder cancer related to tobacco smoking.

Most smoke detectors contain a small amount of the alpha emitter americium-241. This isotope is extremely dangerous if inhaled or ingested, but the danger is minimal if the source is kept sealed. Many municipalities have established programs to collect and dispose off old smoke detectors, rather than let them go into the general waste stream.

2.2.1.8 Neutron

The neutron was discovered in 1932 by the English physicist James Chadwick.[16] The neutron is a particle found in almost every atomic nucleus (the tiny spec of matter at the heart of an atom). Only the hydrogen nucleus has no neutron. All other atoms have one or more. It has no electric charge and its mass is nearly 1,840 times that of the electron. It is then considered to have an atomic number of zero and a mass number of one.

Neutrons and protons constitute almost all of an atom's mass. They stick together because of the strong nuclear force to form all the different kinds of atoms. Like the proton and other baryons, the neutron consists of three quarks.

A free neutron is a neutron that exists outside of an atomic nucleus. While neutrons can be stable when bound inside nuclei, free neutrons are unstable and decay with a lifetime of just under 15 minutes (885.7 ± 0.8 s). The only possible decay mode, via the weak nuclear force, is into a proton, an electron, and an electron antineutrino (antineutrino), the proton and electron forming a hydrogen atom(beta decay):

$$\mathbf{n} \rightarrow \mathbf{p} + \bar{e} + \bar{v}$$

This happened to most of the neutrons created by the big bang. Free neutrons easily pass through atoms, because they have no electrical charge, and so they form highly penetrating radiation, interacting with matter only through collisions with atomic nucleons.

The neutron is important in forming a chain reaction in nuclear fission, as used in nuclear reactors and atom bombs. The absorption of neutrons by other nuclei, exposed to the high neutron densities in nuclear reactors, generates radioactive isotopes useful for a wide variety of purpose.

2.2.2 Sources of Radiation

There are several means by which radiation enters into the earth. But basically the various sources could be classified into either natural sources or man made sources.

2.2.2.1 Natural Background Radiation

Natural background radiation comes from four primary sources: cosmic radiation, solar radiation, external terrestrial sources, and radon.

The earth is constantly bombarded by radiation from outside our solar system of positively charged ions from protons to iron nuclei. The energy of this radiation can far exceed energies that humans can create even in the largest particle accelerators. This cosmic radiation interacts in the atmosphere to create secondary radiation that rains down, including x-rays, muons, protons, alpha particles, pions, electrons, and neutrons.

The dose from cosmic radiation is largely from muons, neutrons, and electrons. The dose rate from cosmic radiation varies in different parts of the world based largely on the geomagnetic field, altitude, and solar cycle. The dose rate from cosmic radiation on aeroplanes is so high that airline workers receive more doses on average than any other worker, including nuclear power plant workers.[13]

While most solar radiation is electromagnetic radiation, the sun also produces particle radiation, solar particles, which vary with the solar cycle. They are mostly protons; these are relatively low in energy (10-100 keV). The average composition is similar to that of the Sun itself. This represents significantly lower energy particles that come from cosmic rays. Solar particles vary widely in their intensity and spectrum, increasing in strength after some solar events such as solar flares. Further, an increase in the intensity of solar cosmic rays is often followed by a decrease in the galactic cosmic rays, called a ‘Forbush decrease’ after their discoverer, the physicist Scott Forbush. These decreases are due to the solar wind which carries the sun's magnetic field out further to shield the earth more thoroughly from cosmic radiation.[14] The ionising component of solar radiation is negligible relative to other forms of radiation on Earth's surface.

Most material on earth contains some radioactive atoms. But most of terrestrial non-radon-dose one receives from these sources is from gamma-ray emitters in the walls and floors when inside the house or rocks and soil when outside. The major radionuclides of concern for terrestrial radiation are potassium, uranium and thorium. Each of these sources has been decreasing in activity since the birth of the Earth so that our present dose from potassium-40 is about ½ what it would have been at the dawn of life on Earth.

Radon-222 is produced by the decay of radium-226 which is present wherever uranium is found. Since radon is a gas, it seeps out of uranium-containing soils found across most of the world and may concentrate in well-sealed homes. It is often the single largest contributor to an individual's background radiation dose and is certainly the most variable from location to location. Radon gas is one of the major causes of lung cancer.

2.2.2.2 Human-made Radiation Sources

By far, the most significant source of human-made radiation exposure to the general public is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy. Some of the major radionuclides used are I-131, Tc-99, Co-60, Ir-192, Cs-137. These are rarely released into the environment.

In addition, members of the public are exposed to radiation from consumer products, such as tobacco (polonium-210), building materials, combustible fuels (gas, coal, and petroleum), ophthalmic glass, televisions, luminous watches and dials (tritium), airport X-ray systems, smoke detectors (americium), road construction materials, electron tubes, fluorescent lamp starters, lantern mantles (thorium), and many others.

Members of the public are exposed to radiation from the nuclear fuel cycle, which includes the entire sequence from mining and milling of uranium to the disposal of the spent fuel. The effects of such exposure have not been reliably measured. Estimates of exposure are low enough that proponents of nuclear power liken them to the mutagenic power of wearing trousers for two extra minutes per year (because heat causes mutation). Opponents use a cancer per dose model to prove that such activities cause several hundred cases of cancer per year.

Occupationally exposed individuals are exposed according to the sources with which they work. The radiation exposure of these individuals is carefully monitored with the use of pocket-pen-sized instruments called dosimeters. Examples of industries where occupational exposure is a concern include:

i. Airline crew (the most exposed population)
ii. Fuel cycle
iii. Industrial radiography
iv. Nuclear Medicine and medical Radiology departments (including Radiation Oncology)
v. Nuclear power plants
vi. Research laboratories (government, university and private)

2.2.3 Sources of Neutrons

Neutron source is a general term referring to a variety of devices that emit neutrons, irrespective of the mechanism used to produce the neutrons. Depending upon variables including the energy of the neutrons emitted by the source, the rate of neutrons emitted by the source, the size of the source, the cost of owning and maintaining the source, and government regulations related to the source, these devices find use in a diverse array of applications in areas of physics, engineering, medicine, nuclear weapons, petroleum exploration, biology, chemistry, nuclear power and other industries. There are several kinds of neutron sources.

2.2.3.1 Small Devices

2.2.3.1.1 Spontaneous Fission (SF)

Certain isotopes undergo spontaneous fission with emission of neutrons. The most commonly used spontaneous fission source is the radioactive isotope californium-252. Cf-252 and all other spontaneous fission neutron sources are produced by irradiating uranium or another transuranic element in a nuclear reactor, where neutrons are absorbed in the starting material and its subsequent reaction products, transmuting the starting material into the SF isotope. When purchased new, a typical CF-252 neutron sources emit between 1×10^7 to 1×10^9 neutrons per second but, with a half life of 2.6 years, this neutron output rate drops to half of this original value in 2.6 years.

2.2.3.1.2 Alpha Reaction

Neutrons are produced when alpha particles impinge upon any of several low atomic weight isotopes including isotopes of beryllium, carbon and oxygen. This nuclear reaction can be used to construct a neutron source by intermixing a radioisotope that emits alpha particles such as radium or polonium with a low atomic weight isotope, usually in the form of a mixture of powders of the two materials.

Typical emission rates for alpha reaction neutron sources range from 1×10^6 to 1×10^8 neutrons per second. As an example, a representative alpha-beryllium neutron source can be expected to produce approximately 30 neutrons for every one million alpha particles. The useful lifetime for these types of sources is highly variable, depending upon the half life of the radioisotope that emits the alpha particles. The size and cost of these neutron sources are also comparable to spontaneous fission sources. Usual combinations of materials are plutonium-beryllium (PuBe), americium-beryllium (AmBe), or americium-lithium (AmLi).

2.2.3.1.3 Sealed Tube Neutron Generator

Some accelerator-based neutron generators exist that work by inducing fusion between beams of deuterium and/or tritium ions and metal hydride targets which also contain these isotopes.

2.2.3.1.4 Photoneutron

Gamma radiation with an energy exceeding the neutron binding energy of a nucleus can eject a neutron. Two examples and their decay products:

Beryllium 9 + 1.7Mev gamma ray → 1 neutron + 2 Helium 4.

Mercury 198 + 6.8Mev gamma ray → 1 neutron + Mercury 197(half-life 2.7 days → Gold 197).

The number of neutrons released by each fission event is dependent on the substance.

2.2.3.1.5 Plasma Focus and Plasma Pinch

The plasma focus neutron source produces controlled nuclear fusion by creating dense plasma within which ionized deuterium and/or tritium gas is heated to temperatures sufficient for creating fusion.

2.2.3.2 Large Devices

Nuclear fission in a reactor produces neutrons which can be used for experiments. This (and not the study of nuclear fission itself) is the purpose of nuclear research reactors. A spallation source is a high-flux source, in which protons that have been accelerated to high energies hit a target material, prompting the emission of neutrons.

Accelerator driven neutron sources**:** The idea of accelerator driven neutron sources goes back to the fifties of last century. The project of a Materials Testing Accelerator in Livermore aimed at the production of fissionable materials.[17] With the success of nuclear reactors for energy production and fuel breeding these projects lost significance. Beam tube reactors became the established neutron sources for scientific activities. Due to technical reasons these research reactors later on turned out to be limited to a flux of thermal neutrons somewhat above 10^{15} n/(cm^{2}s), e.g. ILL (Grenoble). This led to a revival of accelerator driven neutron sources for research purposes in the eighties.

2.2.4 Neutron Flux

For most applications, a higher neutron flux is always better (since it reduces the time required to conduct the experiment or acquire the image). Amateur fusion devices, like the fusor, generate only about 3.0 x 10^5 neutrons per second. Commercial fusor devices can generate on the order of 10^9 neutrons per second, which corresponds to a usable flux of less than 10^5 n/(cm² s). Large neutron beamlines around the world achieve much greater flux. Reactor-based sources now produce 10^{15} n/(cm² s), and spallation sources generate greater than 10^{17} n/(cm² s).

2.3 Interactions of Gamma Radiation with Matter.

2.3.1 Introduction

The instrumental detection of any particle or radiation depends upon the production of charged secondary particles which can be collected together to produce an electrical signal. Charged particles, for example, alpha and beta particles, produce a signal within a detector by ionization and excitation of the detector material directly. Gamma photons are uncharged and consequently cannot do this. Gamma ray detection depends upon other types of interaction which transfer the gamma ray energy to electrons within the detector material. These excited electrons have charge and lose their energy by ionization and excitation of the atoms of the detector medium giving rise to many charged pairs. The absorption coefficient of gamma radiation in gases is low and all practical gamma ray detectors depend on interaction with a solid. The charged pairs produced are electron-hole pairs whose number is proportional to the energy of the electrons produced by the primary interaction.

Gamma spectrometry using germanium detectors is the best technique for identifying and quantifying radionuclides. This is due to the very sharply defined and characteristic energies of gamma-rays which are produced bythe great majority of radionuclides.

2.3.2 Mechanisms of Interaction

In the context of gamma-ray spectroscopy, the three most important interaction processes of photon in matter are photoelectric absorption, Compton scattering and pair production.

Photoelectric interactions are dominant at low energies and pair production at high energy greater than 1.022MeV with Compton scattering being most important in the mid-energy range. Other interaction processes are coherent scattering, (also known as Bragg or Rayleigh scattering) which becomes increasingly important at low energies less than 50keV, and photonuclear reactions at high energies greater than 5MeV.

Coherent scattering involves a re-emission of the gamma ray after absorption with unchanged energy but different direction. Since no energy is transferred to the detector this can play no part in the generation of the detector signal need not be considered further. The cross-sections for photonuclear reactions are not significant for gamma rays of energy less than 5MeV and this mode of interaction can be discounted in most gamma ray measurement situations.

It is important to be aware that each of the significant interaction processes results in the transferred of gamma ray energy to electrons in the absorbing medium, i.e. the gamma ray detector. In all that follows, therefore, the energy transferred to the electrons represents the absorbed by the detector and is, in turn, related to the output from the detector.

The interactions of photons within the source material and in any other matter between the source and the detector leads to an attenuation and modification of the original spectral fluence rate. The attenuation of monoenergetic photons along a path of length r through a uniform material is described by an exponential function

$$I = I_0 e^{-\mu \tau}$$

where I is the number of photons transmitted without change of the original energy; I_o is the number of original photons and μ the linear attenuation coefficient having the dimension of a reciprocal length(e.g. cm^{-1}). An attenuation coefficient is a measure of the reduction in the gamma ray intensity at a particular energy caused by an absorber. The attenuation coefficient is greater for materials with a higher atomic number. Hence germanium is a more satisfactory detector material for gamma rays than silicon. It is different from the absorption coefficient which is related to the amount of energy retained by the absorber as the gamma radiation passes through it. The mass attenuation coefficient μ/ρ (dimension, e.g.,cm^2/g) is independent of the density ρ, of the material and is therefore preferred for the description of the attenuation. The coefficient μ includes coherent scattering in which only the photon direction but not its energy is changed.

2.3.2.1 Photoelectric Absorption

Photoelectric absorption arises by interaction of the gamma-ray photon with one of the bound electrons in an atom. usually the electron of the atom occupies an inner electron orbit in the atom. The photon disappears and the electron is ejected from the atom with a kinetic energy, E_e, given by:

$$E_e = E_\gamma - E_b$$

where E_γ is the gamma ray (photon) energy and E_b the energy binding the electron in its shell as shown in fig.2.1a.

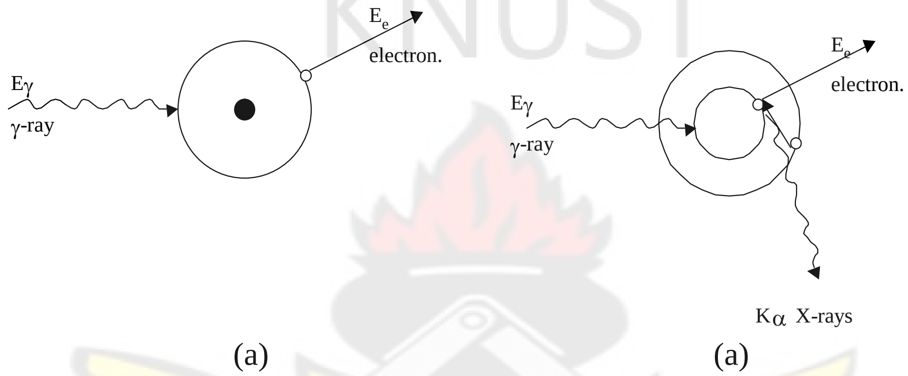

Figure 2.3: Photoelectric Absorption

The atom is left in an excited state with an excess energy of E_b and

recovers its equilibrium in one of two ways. The atom may de-excite by redistribution of the excitation energy between the remaining electrons in the atom. This can result in the release of further electrons from the atom called Auger electrons (secondary electrons) which transfers a further fraction of the total gamma ray energy to the detector. Alternatively, the vacancy left by the ejection of the photoelectron may be filled by a higher energy electron falling into it with the emission of a characteristic X-ray which is called X-ray fluorescence as shown in fig.2.3b

This X-ray may then in turn undergo photoelectric absorption, perhaps emitting further X-rays, which are absorbed in turn until ultimately all the energy of the gamma ray is absorbed. The energy level from which the electron is ejected depends on the energy of the gamma ray. The most likely to be ejected is a K electron. If sufficient energy were not available to eject a K electron then L or M electrons would be ejected instead. This gives rise to the discontinuities in the photoelectric absorption curves. These absorption edges occur at the binding energies corresponding to the electron shells. The probability that a photon will undergo photoelectric absorption can be express as a cross section τ.

This measure of the degree of absorption and attenuation varies with the atomic number, Z, of the absorber and the gamma ray energy, E, in a complicated manner

$$\tau \propto \frac{Z^n}{E_\gamma^m},$$

where n and m are within the range 3 to 5 depending on energy. The significance of this equation is that heavier atoms absorb gamma ray, at least as far as the photoelectric effect is concerned, more effectively than lighter atoms. It follows that ideal detector materials would be of high Z, given that their charge collection characteristics were satisfactory.

The photoelectric attenuation coefficient

$$\mu_{PE}\left(m^{-1}\right) = \tau \times \rho \times \frac{N_A}{A}$$

where ρ is the density of the absorbing material, A its average atomic mass and N_A Avogadro's number

It is normally assumed that photoelectric absorption results in the complete absorption of the gamma ray. However for those events near to the surface of the detector there is a reasonable probability that some fluorescent X-rays, most likely the K X-rays, might escape from the detector. The net energy absorbed in the detector would then be

$$E_e = E_\gamma - E_{k\alpha}$$

where $E_{k\alpha}$ is the energy of the K_α X-ray of the detector material. This process is known as X-ray escape**.** Since a precise amount of energy is lost this gives rise to a definite peak at the low energy side of the full-energy peak. In a germanium detector it would be called a germanium escape peak and in a sodium iodide detector an iodide escape peak**.** Such peaks are usually only significant for small detectors and low energy photons but can be found associated with higher energy gamma ray peaks when these are very well defined.

2.3.2.2 Compton Scattering

Compton scattering is a direct interaction of the gamma ray with an

electron, transferring part of the gamma ray energy as shown in fig2.4

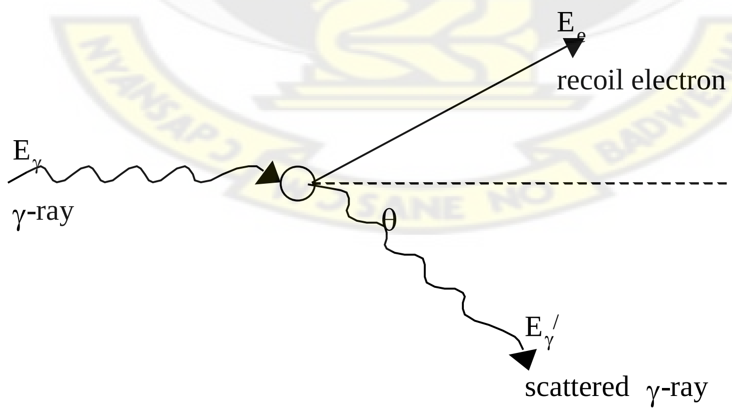

Figure 2.4: Compton Scattering

The energy imparted to the recoil electron is given by the following equation

$$E_e = E_\gamma \left\{ 1 - \frac{1}{\left(1 + \frac{E\gamma[1-\cos\theta]}{m_o c^2} \right)} \right\}$$

or $E_e = E_\gamma - E_{\gamma 1}$

Putting different values of θ into this equation provides a response function with energy. Thus with $\theta = 0^o$, i,e. scattering directly forward from the interaction point, E_e is found to be 0 and no energy is transferred to the detector. At the other extreme when the gamma ray is backscattered and $\theta = 180^o$ the term within the brackets in the equation above is still less than 1 and so only a proportion of the gamma ray energy will be transferred to the recoil electron. At intermediate scattering angles the amount of energy transferred to the electron must be between those two extremes.

Figure 2.5 below shows a schematic diagram showing this relationship.

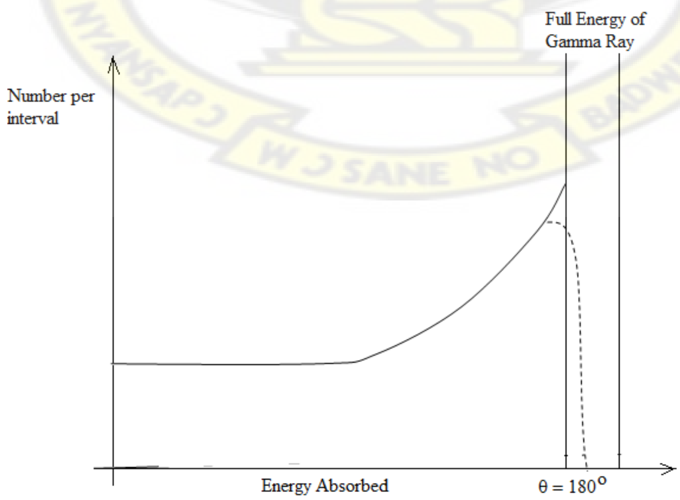

Figure 2.5: Energy transferred to absorber by Compton scattering related to scattering angle.

2.3.2.3 Pair Production

Unlike photoelectric absorption and Compton scattering, pair production results from the interaction of the gamma ray with the atom as a whole. The process takes place within the Coulomb field of the nucleus resulting in the conversion of gamma ray into an electron-positron pair. For this quantum mechanical process to take place at all the gamma ray must carry an energy at least equivalent to the combined rest mass of the two particles (511KeV each), making 1022KeV in all. (In practice, evidence of pair production is only seen within a gamma spectrum when the energy is rather more than 1022KeV).

In principle, pair production can also occur under the influence of the field of an electron but the probability is much lower and the energy threshold is 4 electron masses, making it negligible as a consideration in gamma spectroscopy. The electron and positron created share the excess gamma ray energy equally, losing it to the detector medium as they are slowed down. Figure 2.4 shows the mechanism of pair production.

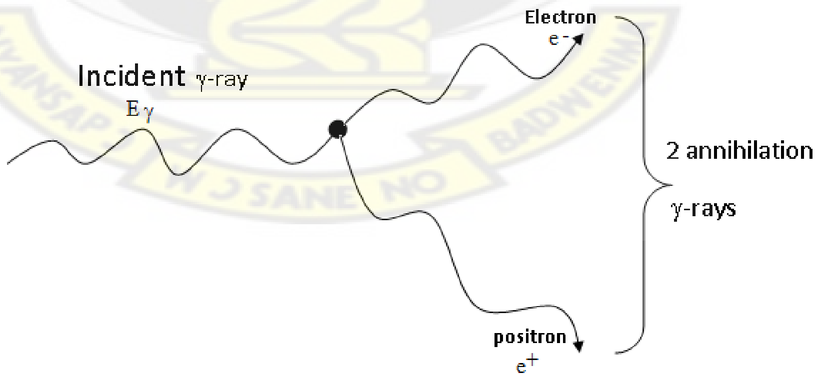

Figure 2.6: The Mechanism of Pair Production

This section critically analyzes the interaction of electromagnetic radiation with matter. On the aspect of ionizing radiation, interactions with matter is sub-grouped into charged particle interactions, photon interactions and neutron interactions.

2.3.3 Particle Interactions

Energetic charged particles interact with matter by electrical forces and lose kinetic energy through excitation or ionization and / or radiative losses. About 70% of charged particle energy deposition leads to nonionizing excitation

Excitation occurs when there is enough energy to raise the electron to a higher energy level but no free electron is created. Ionization occurs when a particle or radiation with sufficient energy can eject one or more electrons from its orbit of the atom or molecule. The average energy dissipated per ionization is about 33 eV.

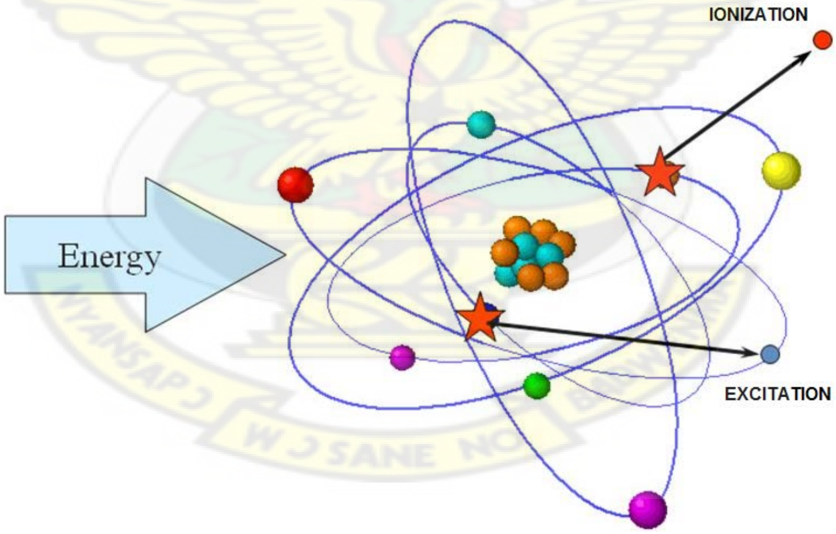

Figure 2.7: Ionization and Excitation Processes in Matter

When a charged particle such as an electron passes near an atom, electrical forces between it and electrons in the atom can result in transfer of energy from the incident particle to the orbital electron. If enough energy is transferred to the orbital electron to overcome its binding energy, this electron will be ejected from the atom

This ejected electron is referred to as a secondary electron. If the secondary electron is energetic enough to create more ionizations, it is known as a delta ray.

It is these ionizations which are mostly responsible for the energy deposited in tissue in the body.

If the energy transferred to the orbital electron is smaller than its binding energy, the electron will not be ejected from the atom, rather it will be left in an excited state, a process known as excitation.

Ionization process results in deexcitation in the production of characteristic radiation and auger electron(s).

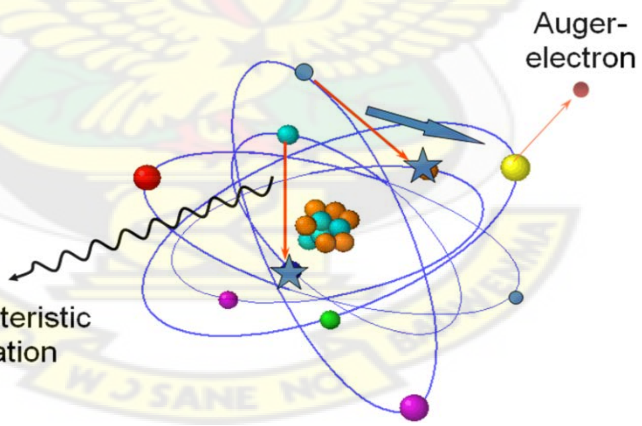

Figure 2.8: De – excitation Process.

When the incident electron penetrates the electron cloud and interacts with the nucleus of the atom. This interaction will cause the incident electron to be deflected and lose considerable energy.

This lost energy appears in the form of "bremsstrahlung" radiation, which literally means "braking radiation".

Bremsstrahlung radiation appears in the form of a photon, and can have any energy up to the full energy of the incident particle

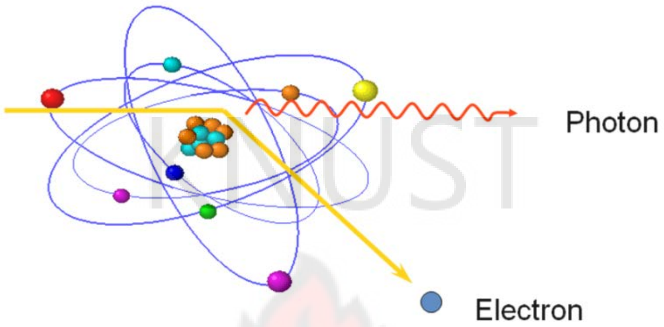

Figure 2.9: Bremsstrahlung Process

2.4 Interactions of Neutrons with Matter

2.4.1 Elastic Collisions

Neutron collides with nucleus. The neutron is deflected with some loss of energy which is transferred to the recoiling nucleus.

The energy E_{tr} transferred to the nucleus of mass M_a by the neutron of mass m, and energy E_n is given by:

$$E_{tr} = E_n \frac{4M_a m}{(M_a + m)^2} \cos^2 \theta$$

where θ is the angle of recoil.

2.4.2 Inelastic Collisions

Neutron is momentarily captured by a nucleus and emitted with diminished energy, leaving the nucleus in an excited state. The nucleus may return to its ground state by emission of a gamma ray.

e.g. $^{16}O\left(n,n'\right)\,^{16}O^{*}$

2.4.3 Nonelastic Collisions

If the particle emitted from the inelastic collision is not a neutron.

e.g. $^{16}O\left(n,\,\alpha\right)\,^{13}C^{*}$

2.4.4 Capture Processes

Thermal neutrons (i.e. neutrons in thermal equilibrium with matter, with energy ~ 0.025 eV) are captured by nuclei.

e.g. $^{1}H\left(n,\gamma\right)\,^{2}H$

2.4.5 Spallation

Neutron causes fragmentation of the nucleus, several particles and nuclear fragments are ejected. The process only becomes significant above ~ 20 MeV

2.5 Asbestos

The word Asbestos is derived from a Greek adjective meaning inextinguishable. It is distinguished from other minerals by the fact that its crystals form long, thin fibres. Deposits of asbestos are found throughout the world. The primary sites of commercial production are: the Commonwealth of Independent States, Canada, Brazil, Zimbabwe, Russia and South Africa.[18]

Figure 2.10: Fibrous Asbestos on Muscovite

Figure 2.11: Asbestos Fibres

Asbestos became increasingly popular among manufacturers and builders in the late 19th century due to its resistance to heat, electricity and chemical damage, sound absorption and tensile strength. When asbestos is used for its resistance to fire or heat, the fibres are often mixed with cement or woven into fabric or mats. Asbestos is used in brake shoes and gaskets for its heat resistance, and on electric oven and hotplate wiring for its electrical insulation at elevated temperature, and in buildings for its flame-retardant and insulating properties, tensile strength, flexibility, and resistance to chemicals.

The inhalation of asbestos fibres can cause serious illnesses, including mesothelioma. Since the mid 1980s, many uses of asbestos are banned in many countries.

2.5.1 Types of Asbestos and Associated Fibres

Six minerals are defined as ‘asbestos’ including: chrysotile, amosite, crocidolite, tremolite, anthophyllite and actinolite.

2.5.1.1 White Asbestos

Chrysotile (white asbestos) is obtained from serpentine rocks which is common throughout the world. The rocks are called serpentine because their fibres curl; chrysotile fibres are curly as opposed to fibres from amosite, crocidolite, tremolite, actinolite, and anthophyllite which are needlelike. Chrysotile, along with other types of asbestos, has been banned in dozens of countries and is only allowed in the United States and Europe in very limited circumstances. Chrysotile is used more than any other type and accounts for about 95% of the asbestos found in buildings in America.[18]

Figure 2.12: Chrysotile asbestos

Applications where chrysotile might be used include the use of joint compound. It is more flexible than amphibole types of asbestos; it can be spun and woven into fabric. Chrysotile, like all other forms of industrial asbestos, has produced tumors in animals.

2.5.1.2 Brown Asbestos

Amosite (brown asbestos), is a trade name for the amphiboles belonging to the Cummingtonite - Grunerite solid solution series, commonly from Africa, named as an acronym from Asbestos Mines of South Africa. One formula given for amosite is $Fe_7Si_8O_{22}(OH)_2$. It is found most frequently as a fire retardant in thermal insulation products and ceiling tiles.[18] This type of asbestos, like all asbestos, is hazardous.

2.5.1.3 Blue Asbestos

Crocidolite (blue asbestos) is an amphibole from Africa and Australia. It is the fibrous form of the amphibole riebeckite. Blue asbestos is commonly thought of as the most dangerous type of asbestos. One formula given for crocidolite is $Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$. This type of asbestos is hazardous.

2.5.1.4 Other Asbestos

Other regulated asbestos minerals, such as tremolite asbestos, $Ca_2Mg_5Si_8O_{22}(OH)_2$; actinolite asbestos (or smaragdite), $Ca_2(Mg, Fe)_5(Si_8O_{22})(OH)_2$; and anthophyllite asbestos, $(Mg, Fe)_7Si_8O_{22}(OH)_2$; are less commonly used industrially but can still be found in a variety of construction materials and insulation materials and have been reported in the past to occur in a few consumer products.

2.5.2 Uses of Asbestos

Asbestos has numerous uses both in history and in contemporary times.

2.5.2.1 Serpentine Group

Serpentine minerals have a sheet or layered structure. Chrysotile is the only asbestos mineral in the serpentine group. In the United States, chrysotile has been the most commonly used type of asbestos. According to the U.S. EPA Asbestos Building Inspectors Manual, chrysotile accounts for approximately 95% of asbestos found in buildings in the United States [18]. Chrysotile is often present in a wide variety of materials, including:

a. joint compound

b. mud and texture coats

c. vinyl floor tiles, sheeting, adhesives

d. roofing tars, felts, siding, and shingles

e. ‘transit’ panels, siding, countertops, and pipes

f. fireproofing

g. caulk

h. gaskets

i. brake pads and shoes

j. clutch plates

k. stage curtains

l. fire blankets

m. interior fire doors

n. fireproof clothing for firefighters

o. thermal pipe insulation

2.5.2.2 Amphibole Group

Five types of asbestos are found in the amphibole group: amosite, crocidolite, anthophyllite, tremolite, and actinolite. Amosite (‘brown’ asbestos), is the second most likely type to be found in buildings, according to the U.S. EPA Asbestos Building Inspectors Guide.[18]

Amosite and crocidolite were formally used in many products until the early 1980s. The use of all types of asbestos in the amphibole group was banned (in much of the Western world) by the mid-1980s and by Japan in 1995. These products were mainly:

a. Low density insulation board and ceiling tiles

b. Asbestos-cement sheets and pipes for construction, casing for water and electrical/telecommunication services

c. Thermal and chemical insulation (i.e., fire rated doors, limpet spray, lagging and gaskets).

2.5.3 Asbestos Related Diseases

Some diseases that have been found to be related to asbestos include the following.

i. asbestos warts – caused when the sharp fibres lodge in the skin and are overgrown causing benign callus-like growths.

ii. pleural plaques – discrete fibrous or partially calcified thickened area which can be seen on X-rays of individuals exposed to asbestos. They do not become malignant or cause other lung impairment.

iii. diffuse pleural thickening – similar to above and can sometimes be associated with asbestosis. Usually no symptoms shown but if extensive can cause lung impairment.

2.5.4 Critics of Safety Regulations

According to Natural Resources Canada, chrysotile asbestos is not as dangerous as once thought. According to their fact sheet, '…current knowledge and modern technology can successfully control the potential for health and environmental harm posed by chrysotile'.[19]

Critics sometimes argue that increased regulation does more harm than good and that replacements to asbestos are inferior. An example is the suggestion by Dixy Lee Ray and others that the shuttle Challenger exploded because the maker of O-ring putty was pressured by the EPA into ceasing production of asbestos-laden putty. However, scientists point out that the putty used in Challenger's final flight did contain asbestos, and failures in the putty were not responsible for the failure of the O-ring that led to loss of the shuttle.[20]

Asbestos was used in the first 40 floors of the World Trade Towers and ended up contaminating the air around lower Manhattan after the towers collapsed. Steven Milloy suggests that the World Trade Center towers could still be standing or at least would have stood longer had a 1971 ban not stopped the completion of the asbestos coating above the 64th floor. This was not mentioned in the National Institute of Standards and Technology's report on the towers' collapse. Insulation that replaced asbestos is believed to have equivalent fire resistance, and any sort of sprayed-on insulation, including asbestos-based material, would have been removed in large areas by the impact of the planes and subsequent explosion.[21]

2.5.5 Substitutes for Asbestos in Construction

Fibreglass insulation was invented in 1938 and is now the most commonly used type of insulation material. Many companies produce asbestos-cement products that are reinforced with asbestos fibres. The products had organic fibres incorporated in them. (One such product was known as Eternit and another Everite now use Nutec fibres which consist of organic fibres, portland cement and silica.[22])

Another potential fibre is Polybenzimidazole or PBI fibre. Polybenzimidazole fibre is a synthetic fibre with no melting point that also does not ignite. Due to its exceptional thermal and chemical stability, it is often used by fire departments and space agencies.

2.5.6 Electrical Properties of Asbestos

The electrical properties of asbestos, mica, ceramic, glass, and silica fibre papers have been studied for possible use as thermally stable insulators. The dielectric constants of the synthetic fibre inorganic papers are of the order of 1.05 - 1.15; the densities are correspondingly low (0.2 - 0.3 gm/cc). The dielectric constants of the naturally occurring inorganic papers are higher (3.5) due to the correspondingly higher densities. The electrical losses are lowest in the synthetic base papers (0.0001) and highest in the asbestos products (0.6).[23]

2.6 Electrical impedance

Electrical impedance, or simply impedance, describes a measure of opposition to a sinusoidal alternating current (AC). Electrical impedance extends the concept of resistance to AC circuits, describing not only the relative magnitudes of the voltage and current, but also the relative phases. In general impedance is a complex quantity $\tilde{Z}$ and the term complex impedance may be used interchangeably; the polar form conveniently captures both magnitude and phase characteristics,

$$\tilde{Z} = Ze^{j\theta}$$

where the magnitude gives the change in voltage amplitude for a given current amplitude, while the argument gives the phase difference between voltage and current. In Cartesian form,

$$\tilde{Z} = R + jX$$

where the real part of impedance is the resistance and the imaginary part is the reactance (Figure 2.3). Dimensionally, impedance is the same as resistance; the SI unit is the ohm. Note that while reactance can be either positive or negative, resistance is always positive.

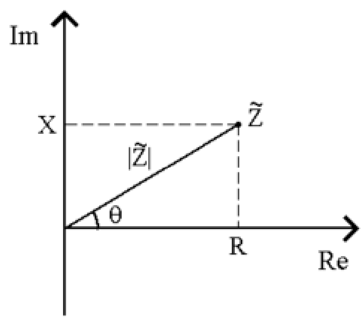

Figure 2. 13: A Graphical Representation of the Complex Impedance Plane.

2.7 Conclusion

Radiations are everywhere; and every matter receives radiation and emits radiation. In many cases the amount and type of radiation received differs from that emitted by the same substance. A high dose of ionising radiation can alter both the chemical and physical characteristics of matter.

Asbestos is one of the substances that is widely used and has very high applicability in industry and construction. It is especially required in conditions where there is high intensity of radiation due to its relatively inert characteristics to most of the radiations, chemicals and electricity. Due to the special qualities of asbestos which makes it most suitable for many purposes, it finds its way into many products and industries even though strict ban has been placed on its production and usage in many countries.

Asbestos is used as electrical insulator in places where there is high temperature like the ovens and the smelters; and places where there is a high flux of radiation like the nuclear reactors. In the nuclear reactor there is one of the most penetrating radiations – neutron radiation; which is also in the air. The literature reviewed suggests asbestos will not maintain its properties under a continual influx of neutron irradiation. This has necessitated the current project on 'The effect of neutron irradiation on the electrical impedance of asbestos'.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The data for the project was collected through experimental design. Experimental design and analysis is an essential part of scientific method. It is one of the most powerful research methodologies researchers can use. Of the many types of research, it is the best way to establish cause-and-effect relationships between variables. Experimental research enables researchers to go beyond description and prediction, beyond identification of relationships, to at least a partial determination of what causes them.

Yet experiments are not always easy to conduct. Every experiment should be well designed, planned and managed to ensure that the results can be analysed, interpreted and presented.

3.2 Project Design

There are different types of research designs employed by scientists. The design adopted in this project is referred to as response experiment research design. This research design is often intended to establish the relationship between the material's properties and other factors that the researcher can control. The properties are called response variables (the dependent variables). The other factors that influence the response variables are called control variables (the independent variables). The statistical objectives of designed response experiments are to specify

i. the number of observations;

ii. the values of the control variables at every observation;

iii. the order of the observations;

with the view to

i. ensuring that all effects in the model can be estimated from the observed data;
ii. testing the reality of those effects by comparison with random variation;
iii. ensuring that all effects can be estimated with the greatest possible precision (reducing the influence of random variation);
iv. ensuring that all effects can be estimated with the least possible bias, or greatest accuracy (reducing the effect of time dependent errors);
v. suggesting improvements to the model;
vi. keeping within a budget of effort and cost.

The variable that is studied is often called the response variable because it changes in response to changes in other variables. In addition, it is a characteristic of the sample by which its usefulness is judged. In this particular project the response variable is the electrical impedance of the asbestos. It is shown along the vertical or Y axis. The variable that influenced or controlled the response variable is, in this case the neutron level in the sample. It is shown along the horizontal or X axis. All of the variables that may influence the response are collectively call explanatory or predictor variables. Other variables like temperature, electric potential and the relative humidity of the air may also influence the electrical impedance of the asbestos. Such variables are called concomitant variables or covariates. For this project, temperature, electric potential and relative humidity are controlled by performing the experiment and taking the measurements in the same place and within the same period of time.

3.3 Sample Preparation

The samples were prepared on 1st to 3rd September, 2007. The process in the preparation of the sample was as follows.

i. A sheet of brown asbestos (amosite – $Fe_7Si_8O_{22}(OH)_2$) ceiling tile was obtained. It was an old broken one (Figure 3.1).

Figure 3.1: Asbestos tiles and the tools used to cut it

ii. The sheet was cut and filed into pieces of dimensions 20mm x 15mm x 5mm. The cutting was done manually using hacksaw blades and files. They were cut to conveniently fit into the probes of the Impedance/ Gain Phase Analyser. Twenty pieces with correct shapes and sizes were selected. (Figure 3.2)

Figure 3.2: Cut pieces of Asbestos and the Storage Box.

iii. The selected pieces were paired and labelled 00 to 09. The Impedance/Gain Phase Analyser has two probes. So the impedances of the pairs were measured at a time.

iv. The samples were stored in a plastic container with lid. Foam with slots cut in it to hold the sample pairs were put into the container. The foam was to give support to the samples and to keep the pairs separated and from contamination by other pairs (Figure 3.3).

Figure 3.3: Pairs of Asbestos pieces place inside Storage Box.

3.4 Equipment for the Experiment

Beside the powered and specialised machines that were used the following hand implements were used.

i. Hacksaw: This is a handsaw with a small-toothed steel blade stretched taut across a frame, used for cutting metal and other hard material.

ii. File: A metal tool, usually long and narrow and with sharpened ridges on one or more of its surfaces, that is used to smooth down or wear away wood, metal or any hard surface.

3.4.1 Miniature Neutron Source Reactor

Research reactors are nuclear reactors that serve primarily as a neutron source. They are also called non-power reactors, in contrast to power reactors that are used for electricity production, heat generation, or submarine propulsion.[17]

The neutrons produced by a research reactor are used for non-destructive testing and analysis of materials, production of radioisotopes, research and public outreach and education. Research reactors that produce radioisotopes for medical or industrial use are sometimes called isotope reactors. Reactors that are optimised for beamline experiments nowadays compete with spallation sources.

Figures 3.4 – Figure 3.6 are some components of the Miniature Neutron Source Reactor at the National Nuclear Reactor Institute, Kwabenya. It was used to irradiate the samples with neutrons. The Rabbit Channel (Pneumatic Transfer Type A) sends the samples into the reactor to be irradiated. The irradiated samples return to the Lead Shield to be collected. After the samples were collected they were put in the Cooling Chamber to cool down. That is for the emission levels to reduce to allowable levels before handling. It was reduced to about 300 nSev/s.

Figure 3.4: Rabbit Channel (Pneumatic Transfer Type A)

Figure 3.5: Lead Shield.

Figure 3.6: Cooling Chamber

3.4.2 Radiation Detector (Geiger – Muller (G-M) Counter)

An instrument used to detect and record the intensity of ionising radiation by detecting particles from a radioactive substance. In Figure 3.7, the G-M counter was used to measure the radiation emission rate of the samples after they were irradiated and allowed to cool and returned into the storage box.

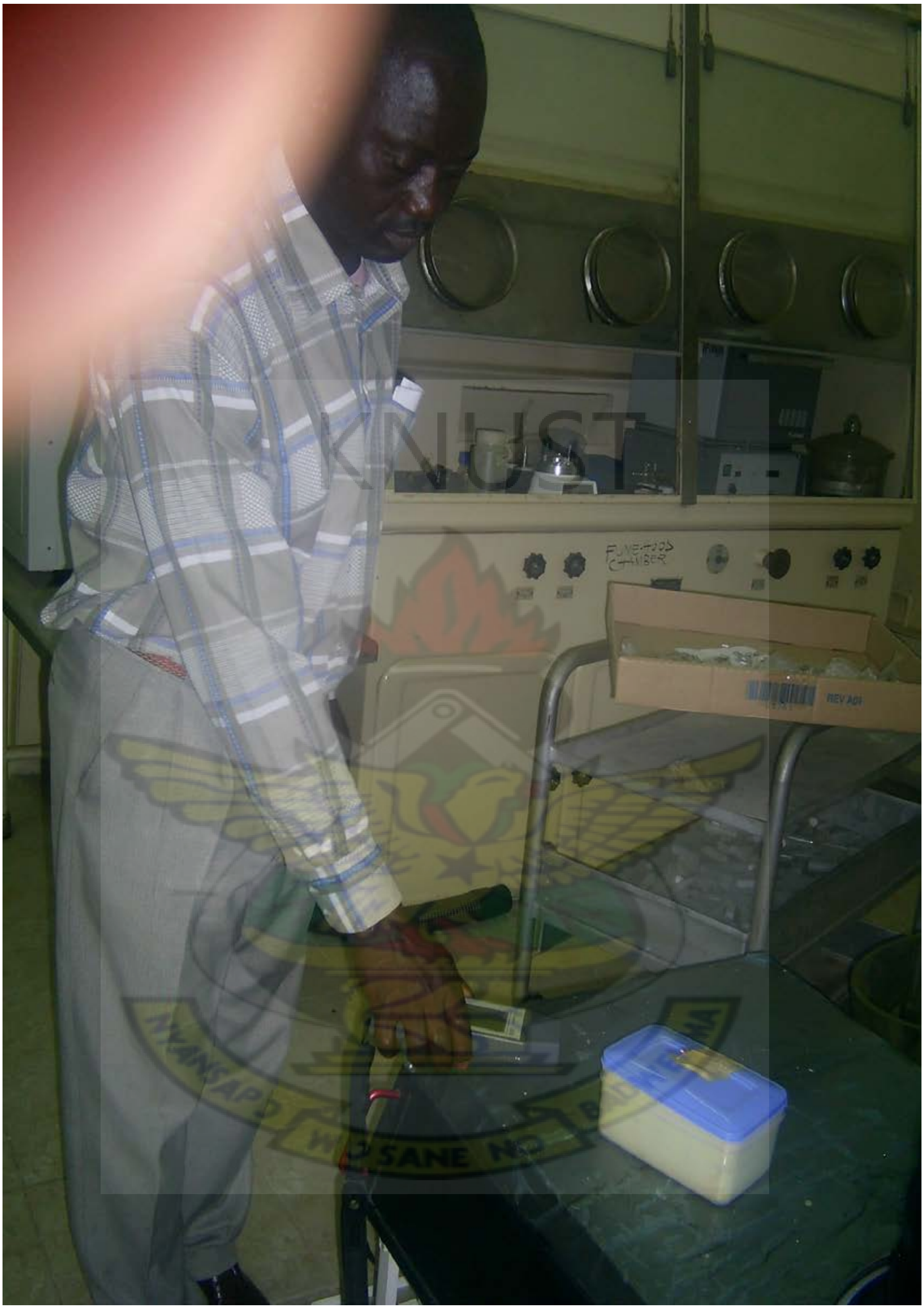

Figure 3.7: A Geiger-Muller Counter used to Measure the Rate of Emission of Radiation.

3.4.3 HP Agilent 4194A, Impedance/Gain-Phase Analyzer

This is an integrated solution for efficient measurement, testing, and analysis of components and circuits. Detailed impedance and transmission characteristics, including secondary parameter derivations, can be simply and quickly evaluated or tested. The HP 4194A (Figure 3.8) can contribute to improving engineering productivity and reducing test cost.

Figure 3.8: HP Agilent 4194A Impedance/Gain-Phase Analyzer.

The analyser is flexible and has wide measurement capabilities in both electrical impedance and transmission measurements. It is also fully programmable using Auto Sequence Programming (ASP). Desired measurements and computations, including graphic analysis, can be programmed simply by storing front-panel keystroke operations, allowing you to customize measurement, computation, and analysis functions. The HP 4194A also features high accuracy and error elimination functions to ensure reliable measurements.[24]

The Features of the HP 4194A Impedance/Gain-Phase Analyzer include:

i. High accuracy and wide range impedance measurement.

ii. Flexible measurement, computation, and analysis capabilities on a colour graphic display.

iii. Fully programmable.

3.5 Procedure for the Experiment

The procedure for the experiment was as follows;

i. The impedances of the samples were measured in pairs with the Impedance/Gain Phase Analyser. The lower and upper values were recorded, and the mean values calculated for each pair. This was done on 4th September, 2007.

ii. The samples were then irradiated in pairs to different levels of neutron radiation. The Miniature Neutron Source Reactor at the National Nuclear Research Institute was employed. The samples were irradiated with a neutron flux of 5 x $10^{11}ncm^{-2}s^{-1}$ at increasing time intervals of 30 minutes. Sample pair 00 was not irradiated; then pair 01 was irradiated for 30 minutes; pair 02 for 1 hour; and so on till pair 09 was irradiated for 4 hours. This was done on 3rd and 4th of October, 2007.

iii. The samples were monitored until the radiation emission level was 300 nSev/s. The impedances of the samples were measured once again in their usual pairs and the values recorded. The second impedance measurement was done on 16th November, 2007.

iv. After the second impedance measurement was taken it was discovered that the impedance of sample pair 00 was also reduced even though it was not irradiated with neutrons. As such the impedance of a sample pair X of which its initial impedance was measured but was not kept in the same storage box, was measured the second time, on 17th of November 2007.

3.6 Precautions

The project involved several risk factors. The health risk in the use of asbestos has been well established over the years. By the first century, Greeks and Romans had already observed, at least in passing, that slaves involved in the weaving of asbestos cloth were afflicted with a sickness of the lungs, which is now understood to be cancer of the lungs [18]. Asbestos can also cause asbestos warts – caused when the sharp fibres of asbestos lodge in the skin and are overgrown causing benign callus-like growths.

It has also been known for many years that large doses of ionising radiation, very much larger than background levels, can cause a measurable increase in cancer and leukaemia ('cancer of the blood') after some years delay. It must also be assumed, because of experiments on plants and animals, that ionising radiation can also cause genetic mutations that affect future generations, although there has been no evidence of radiation-induced mutation in humans. At very high levels, radiation can cause sickness and death within weeks of exposure.

The degree of damage caused by radiation depends on many factors. Dose, type of radiation, the part of the body exposed, age and health, for example, are some factors. Embryos including the human foetus are particularly sensitive to radiation damage.

These issues call for stringent measures to reduce the risk element. The following precautions were taken.

i. Limiting the exposure time: Deliberate effort was made not to linger around the radiation source and not to let the samples be around for long time. Limiting or minimizing the exposure time will reduce the dose from the radiation source.
ii. A reasonable distance was also always kept from the samples and from the radiation source: Radiation intensity decreases sharply with distance, according to an inverse square law.
iii. Shielding by the use of tongs, hand gloves and lead apron. The lead shield and the cooling chamber were all ways of giving effective protection from radiation such as gamma rays and neutrons.
iv. Containment: The samples were confined in the smallest possible space in a box and kept out of the environment.

3.7 Data Processing and Analysis

The data collected was tabulated on tables. The lower and higher values of the impedances of each pair of samples were recorded and the average values determined and recorded. This was done for both when the samples were not irradiated with neutrons and after they were irradiated. The duration of irradiation and the neutron flux density for each sample pair was recorded and tabulated. Linear charts of the average impedances of the sample pairs before and after being irradiated with neutrons were also plotted. The slopes were determined. A regression line was plotted for the average impedance after irradiation (AIAI) of the samples against neutron flux density that passed through the sample pairs.

Experimental research is a quantitative research; and yields quantitative data (ratio scale). The most appropriate statistics for analysing such a data are sample means and standard deviations. The means and standard deviations of the average impedance before irradiation (AIBI) and for average impedance after irradiation (AIAI) of the samples were determined and compared to see whether the neutron irradiation led to an increase, decrease or no effect in the impedance of the samples. The slopes and regression coefficient of the linear charts were also determined. Analysis of the data was done using Microsoft Excel 2007.

3.8 Validation of the Study

The major task in the use of experimental research and particularly laboratory research is how to ensure internal validity. Validity refers to the appropriateness, meaningfulness, and usefulness of the specific inferences made, based on the data collected. Validation is the process of collecting evidence to support such inferences.[25] In research terms, validity refers to the accuracy and truthfulness of the data and findings that are produced. It refers to the concepts or constructs that are being investigated; the samples or objects that are being studied; the methods by which data are collected; and the findings that are produced. Validity therefore depends on the amount and type of evidence there is to support the interpretations made concerning data collected.

There are basically two forms of validity; external validity and internal validity. External validity refers to the degree to which the results of the study can be generalised, or applicable, to groups and environments outside the research setting.

Internal validity on the other hand refers to the degree to which the observed differences on the dependent variable are directly related to the independent variable, and not to 'some other' (uncontrolled) variable. How external validity of the study is checked has been considered under the delimitations of the study. The concentration here is on the threats to internal validity and how to control it. The following approaches were employed to ensure internal validity of the study.

i. The samples were all prepared from the same asbestos sealing sheet.

ii. The measurements of impedance of the samples were done for all the samples at the same time period of about two hours; at the same place and using the same machine.

iii. The neutron irradiation was done within two days consecutively.

iv. Sample pair '00' was not irradiated to serve as a control pair to be compared with the irradiated samples.

v. The impedance of another control sample pair 'X' that was not stored in the same box with the other samples was measured and compared with the impedances of the irradiated samples. The second impedance measurement of sample pair X was taken on 17th November, 2007.

3.9 Statistical (or Hypothesis) Testing

In statistical testing the data obtained from the sample is used to make a decision about whether or not the null hypothesis should be rejected. The numerical value obtained from the statistical test is called the test value. The test value is compared with the critical value. If the difference is significant, the null hypothesis is rejected. If it is not, then the null hypothesis is not rejected.

Significance level: The level of significance is the maximum probability of committing a type 1 error. A type 1 error is committed if the null hypothesis is true and it is rejected. If the null hypothesis is false and it is not rejected, then a type 2 error is made. The level of significance is symbolized α. That is, P(type 1 error) = α. For experimental research a significance level of 0.05 is acceptable.[26]

The t test for paired means was used to compare the mean impedances of the samples before and after the irradiation to see if any observed difference is significant. The t test is used when:

i. The data is quantitative data - ratio scale. The ratio scale is quantitative data that possess true (absolute) zero value. The intervals between points on the scale are equal.

ii. The sample size is small; that is, $n < 30$.

iii. The population standard deviation, σ, is not known.

iv. When the population is normally or approximately normally distributed.

The formula for the t test is

$t = \frac{\bar{X}-\mu}{s/\sqrt{n}}$; where

μ = mean of AIBI (μ_B);

$\bar{X}$ = mean of AIAI (μ_A);

s = standard deviation of AIAI; and

n = sample size, n = 10.

The degrees of freedom are d.f. = n -1 = 10 – 1= 9.

Standard Error: The standard deviation of the sample means is called the standard error. Hence the standard error, $S.E. = \sqrt{\frac{\sigma_B^2}{n} + \frac{\sigma_A^2}{n}}$

3.10 Conclusion

This project is an experimental research on the effect of neutron irradiation on the electrical impedance of asbestos. It yields quantitative data. The mean impedance of the same sample of asbestos before and after they were irradiated with neutrons was compared to find if there exist any significant difference between them. The t test was employed in testing the significance of the findings.

CHAPTER FOUR: RESULTS, FINDINGS AND DISCUSSIONS

4.1 Introduction

The data collected through the experiments were presented on tables. Since the data was of the ratio scale, they were analysed mainly by means, standard deviation and, regression coefficient. Regression lines were also plotted.

4.2 Presentation of Results

The data for the various measurements that were taken were presented on Tables 4.1 – 4.4. Table 4.1 shows the results obtained for the impedance measurements for the samples before they were irradiated with neutrons. The table gives the lower and the upper values for each pair and the average for each pair calculated. The HP Agilent 4194A Impedance/Gain Phase Analyzer displayed the results at a frequency of 20,000,050.00Hz.

Table 4.1: First Impedance Measurement (with samples not irradiated).

SAMPLE	IMPEDANCE (kΩ)		
	LOW	HIGH	AVERAGE(AIBI)

0	288.67	300.10	294.39
1	295.77	299.67	297.72
2	289.72	291.29	290.51
3	293.15	302.29	297.72
4	288.10	302.51	295.31
5	290.39	301.01	295.70
6	286.23	305.19	295.71
7	289.02	302.83	295.93
8	284.87	296.24	290.56
9	293.19	303.43	298.31
MEAN	289.91	300.46	295.48

Frequency = 20,000,050.00Hz; Standard Deviation of AIBI, σ = 2.859kΩ.

The Table 4.2 shows the duration in hours that each sample pair was exposed to the neutron flux. It also shows the neutron flux density (= neutron flux density per second x time of exposure). The flux density per second that each sample pair was exposed to was 5.0 x 10^{11} neutrons per centimetre square per second.

Table 4.2: Neutron Irradiation Levels of Samples.

SAMPLE	DURATION OF EXPOSURE/ hour	NEUTRON FLUX DENSITY/ x 10^{11} neutrons/cm^2
0	0.00	0.00
1	0.50	2.50
2	1.00	5.00
3	1.50	7.50
4	2.00	10.00
5	2.50	12.50
6	3.00	15.00
7	3.50	17.50
8	4.00	20.00
9	4.50	22.50
MEAN	2.25	11.25

Neutron Flux Density per Second = 5 x 10^{11} $ncm^{-2}s^{-1}$.

The Table 4.3 shows the impedance values after the samples were irradiated with neutrons. Here again, the lower and the upper values were recorded and the average values calculated for each sample pair. Measurement was done at the same display frequency (i.e., 20000050.00Hz) of the HP Agilent 4194A, Impedance/Gain-Phase Analyser.

Table 4.3: Second Impedance Measurement (with samples irradiated).

SAMPLE	IMPEDANCE (kΩ)		
	LOW	HIGH	AVERAGE(AIAI)
0	275.34	296.02	285.68
1	277.42	291.18	284.30
2	278.54	279.80	279.17
3	271.35	298.38	284.87
4	270.46	285.20	277.83
5	264.90	303.12	280.01
6	265.10	295.70	280.40
7	263.58	296.40	279.92
8	261.46	295.02	278.24
9	261.20	284.20	273.70
MEAN	268.94	292.50	280.52

Frequency = 20000050.00Hz; Standard Deviation of AIAI, s = 3.669 kΩ.

In Table 4.4, the values for the average impedances (AIBI and AIAI) are recorded; there is also the time of exposure and neutron flux density for each sample pair.

Table 4.4: Average Impedances before and after Irradiation (with sample 00).

SAMPLE	AV. IMP. BEFORE IRRADIATION (AIBI)/kΩ	DURATION OF EXPOSURE/ HOURS	NEUTRON FLUX DENSITY (NFD) / x 10^{11} NEUTRONS/CM^2	AV. IMP. AFTER IRRADIATION (AIAI)/kΩ

0	294.39	0.00	0.00	285.68
1	297.72	0.50	2.50	284.30
2	290.51	1.00	5.00	279.17
3	297.72	1.50	7.50	284.87
4	295.30	2.00	10.00	277.83
5	295.70	2.50	12.50	280.01
6	295.71	3.00	15.00	280.40
7	295.93	3.50	17.50	279.92
8	290.56	4.00	20.00	278.24
9	298.31	4.50	22.50	273.70
MEAN	295. 91	2.25	11.25	280.52

Frequency: 20000050.00Hz; Neutron Flux: 5.0 x $10^{11}ncm^{-2}s^{-1}$.

The Fig. 4.1 is a linear chart of AIBI and AIAI for the various sample pairs plotted on the same Cartesian plane. While the AIBI line is a horizontal line, the AIAI line dipped negatively.

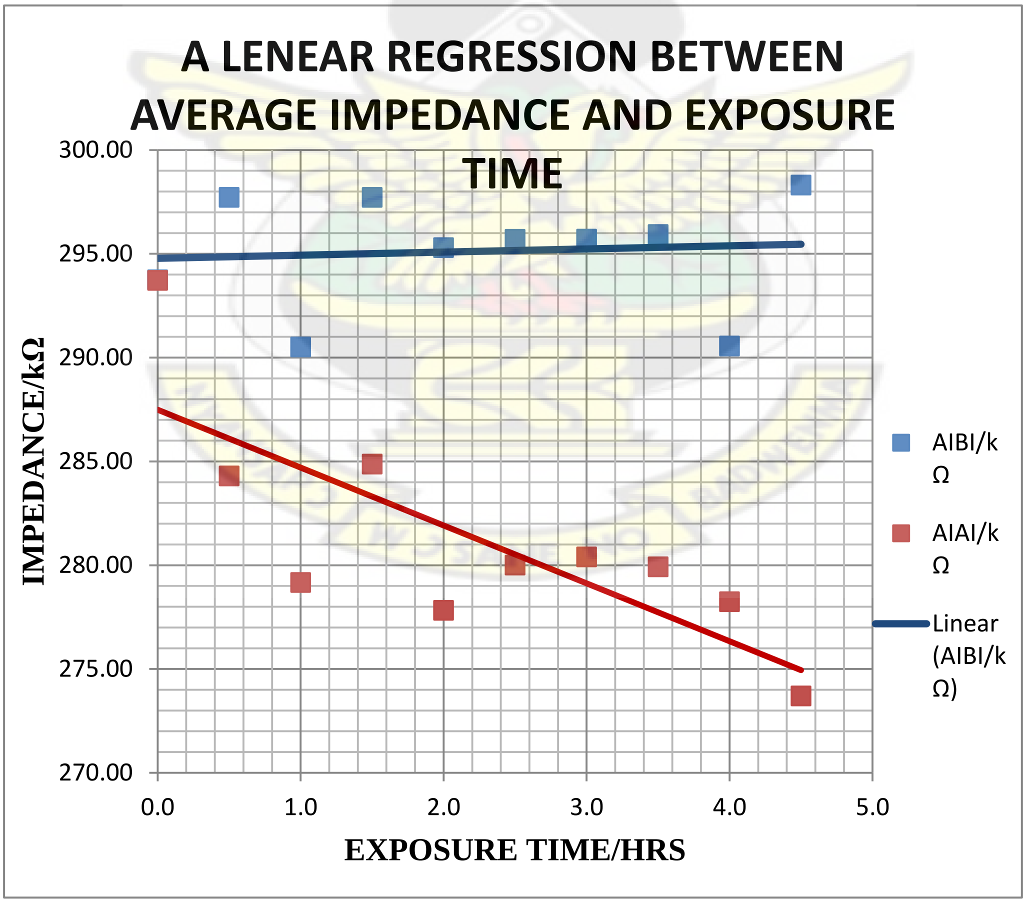

Figure 4.1: Linear Charts of AIBI and AIAI for Sample pairs against Exposure Time (with sample pair 00).

The Fig. 4.2 is the regression line between AIAI and NFD for the sample pairs. It is dipped negatively.

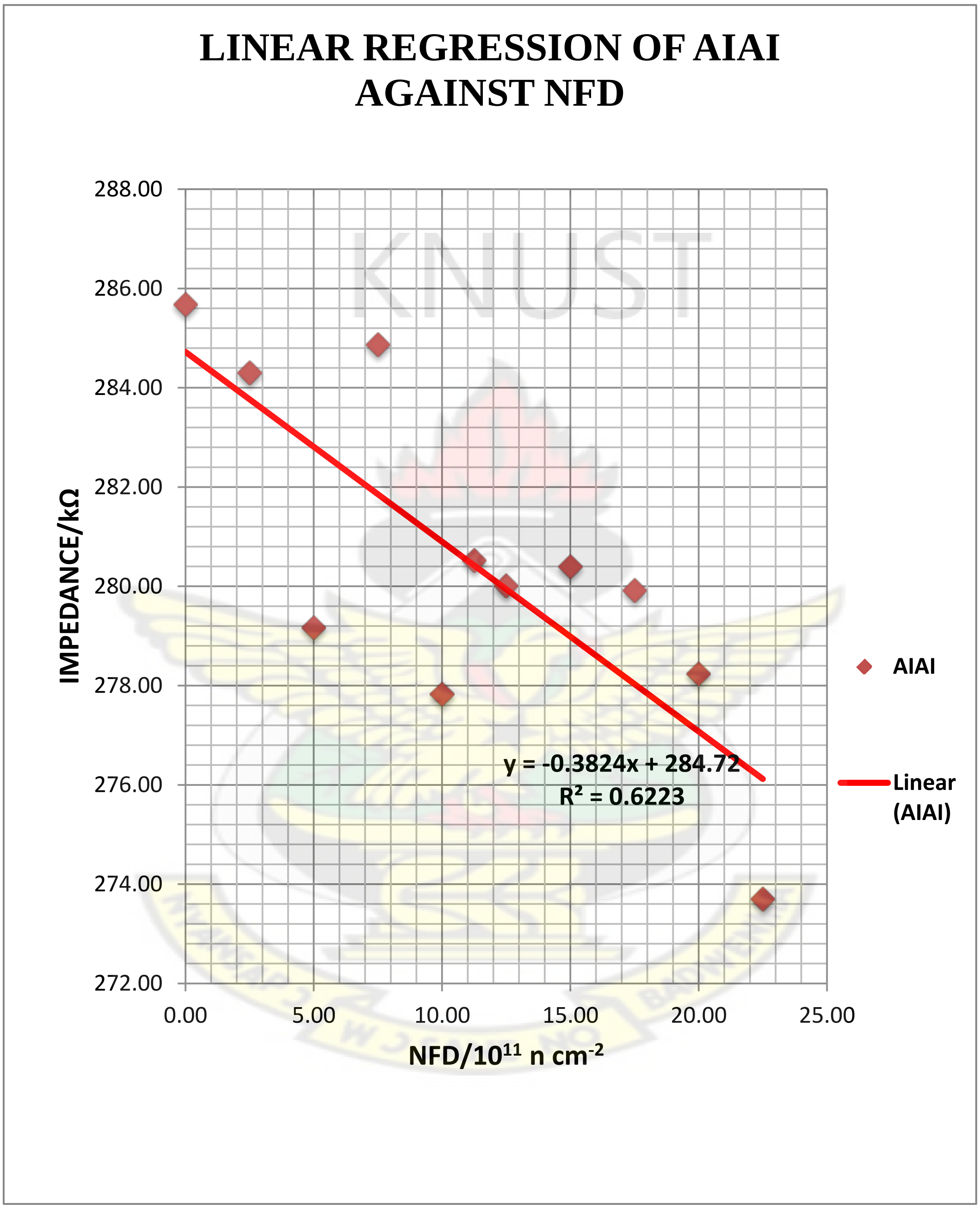

Figure 4.2: Linear Regression between AIAI and NFD (with sample pair 00).

With sample pair 00 replaced by sample pair X, the following tables (Table 4.5 and Table 4.6) and charts (Fig. 4.3 and Fig. 4.5) are obtained.

Table 4.5: Average Impedances before and after Irradiation (with sample pair 00 replaced by X)

SAMPLE	AIBI/kΩ	AIAI/kΩ
X	293.75	293.72
1	297.72	284.30
2	290.51	279.17
3	297.72	284.87
4	295.30	277.83
5	295.70	280.01
6	295.71	280.40
7	295.93	279.92
8	290.56	278.24
9	298.31	273.70

Table 4.6: Neutron Irradiation Levels of Samples and Average Impedance (with sample pair 00 replaced by X).

SAMPLE	NEUTRON LEVEL (NFD)/ x 10^{11} neutrons/cm^2	AV. IMP. AFTER IRRADIATION (AIAI)/kΩ
X	0.00	293.72
1	2.50	284.30
2	5.00	279.17
3	7.50	284.87
4	10.00	277.83
5	12.50	280.01
6	15.00	280.40
7	17.50	279.92
8	20.00	278.24
9	22.50	273.70
MEAN	11.25	281.22

Standard Deviation (AIAI): 5.416/ kΩ

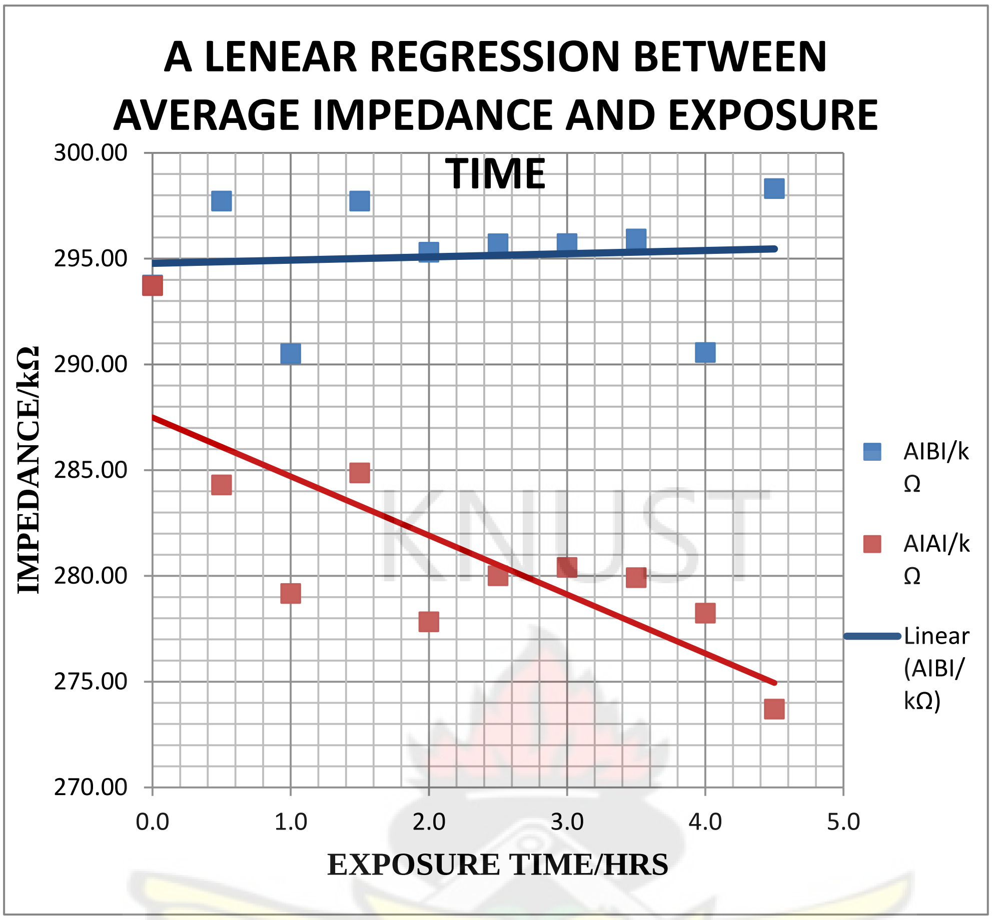

Figure 4.3: Linear Charts of AIBI and AIAI for Sample Pairs against Exposure Time (with sample pair 00 replaced by X).

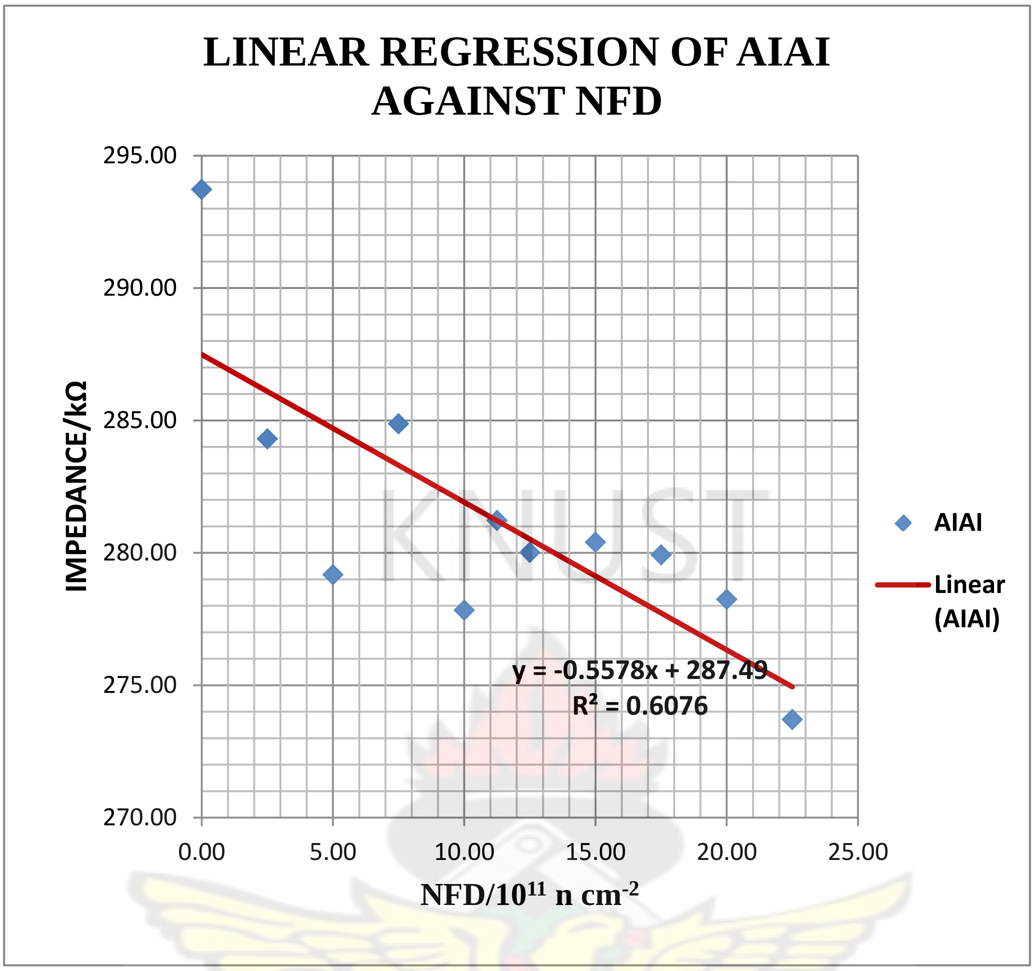

Figure 4.4: Linear Regression between AIAI and NFD (with sample pair 00 replaced by X).

4.3 Findings of the Project

The following findings have been made from the results of the study (Table 4.1 to Table 4.5).

1. The mean value of AIBI, μ_B = 295.91 kΩ; and that for AIAI, $\bar{X}$ (or μ_A) = 280.52 kΩ; a difference in means of about 15.39 kΩ, when sample pair 00 is used. But $\bar{X}$ (or μ_A) = 281.22 kΩ; a difference in means of about 14.69 kΩ, when sample pair X is used.

2. The average impedance of sample pair 00 was lowered by a margin of about 8.71 kΩ (i.e., 294.39 kΩ – 285.68 kΩ); even though it was not irradiated with the neutrons.

3. The impedance of sample pair X remained relatively the same (a difference of 0. 03 kΩ). The impedance values of sample pair X were as shown in Table 4.7.

Table 4.7: Impedance of Sample Pair X.

MEASUREMENT SESSIONS	IMPEDANCE/ kΩ		
	LOW	HIGH	AVERAGE
FIRST	290.17	297.32	293.75
SECOND	290.25	297.19	293.72
MEAN	290.21	297.26	293.74

Frequency: 20,000,050.00Hz.

4. The regression coefficient between AIAI and NFD (R-Square) is 0.622 with sample pair 00; and 0.607 with sample pair X.

5. From Figures 4.2 and 4.4, AIAI and NFD are related by the linear expression,

   AIAI = 284.7 – 0.382NFD (with sample pair 00); and

   AIAI = 286.7 – 0.557NFD (with sample pair X); NB:

   AIBI and AIAI are in kΩ; NFD is in 10^{11} neutrons/cm^2

6. The standard deviation of AIBI, σ_B = 2.86kΩ; and the standard deviation of AIAI, is s_0 = 3.67kΩ with sample pair 00, and σ_A = 5.42kΩ with sample pair X.

4.4 Discussion of the Results

The results indicate that the mean impedance of the samples has reduced after the irradiation with neutrons. This may be due to the emission of beta particles – electrons. Literature reviewed indicated that when an element is bombarded with neutrons, it undergoes gamma decay and then beta decay.[27] That is,

$$ {}^{1}_{0}n + {}^{A}_{Z}X \rightarrow {}^{A+1}_{Z}X + \gamma. $$

The ${}^{A+1}_{Z}X$ nucleus is excited for a very short time before it undergoes gamma decay. Also, the product nucleus ${}^{A+1}_{Z}X$ is usually radioactive and decay by beta emission; i.e.

$$ {}^{A+1}_{Z}X \longrightarrow {}^{A+1}_{Z+1}Y + {}^{0}_{-1}e. $$

Since the formula for amosite is $Fe_7Si_8O_{22}(OH)_2$ any of the following reactions could have taken place:

1. $${}^{56}_{26}Fe + {}^{1}_{0}n \rightarrow {}^{57}_{27}Co + {}^{0}_{-1}e .$$

2. $${}^{28}_{14}Si + {}^{1}_{0}n \rightarrow {}^{29}_{15}P + {}^{0}_{-1}e.$$

3. $${}^{16}_{8}O + {}^{1}_{0}n \rightarrow {}^{17}_{9}F + {}^{0}_{-1}e.$$

4. $${}^{1}_{1}H + {}^{1}_{0}n \rightarrow 2\,{}^{1}_{1}H + {}^{0}_{-1}e.$$

This is what would have led to the release of free electrons into the asbestos making it more conducting to current and so lowering the electrical impedance.

An interesting observation is the finding that the average impedance of sample pair 00 was lower during the second impedance measurement. Sample pair 00 was not irradiated with neutrons; but it was stored in the same box with the other samples that were irradiated. They might therefore have absorbed some beta particles (free electrons) released by the irradiated samples, thereby reducing its impedance. This is supported by the finding that the average impedance of sample pair X was nearly constant, i.e., 293.75 kΩ for the first measurement and 293.72 kΩ for the second measurement. It is not certain whether the 0.03 kΩ reduction in impedance was actually due to the delay in time.

Expressions linking AIAI and NFD are:

$$\text{AIAI} = 284.7 - 0.382\text{NFD, i.e., } Z = 284.7 - 0.382\Phi$$

when sample pair 00 is used; and

$$\text{AIAI} = 287.4 - 0.557\text{NFD, i.e., } Z = 287.4 - 0.557\,\Phi$$

when sample pair X is used (NB: Z is in kΩ; and Φ is in 10^{11} neutrons/cm^2).

These expressions between AIAI and NFD suggest a linear relation between the electrical impedance of the asbestos samples that were used in the study and neutron flux density that pass through the samples. Since sample pair 00 might have been contaminated as a result of it being kept in the same box with the irradiated samples, it would be preferable using the results obtained with sample pair X. By manual calculation, the intercepts on the AIAI and NFD axes are 287.4 kΩ and 5.16 x 10^{13} n/cm^2 respectively, (i.e. with sample pair X).

4.5 Effect of Neutron Irradiation on Impedance of Asbestos

Without neutron irradiation the mean impedance of the asbestos samples was

μ_B = 295.91 kΩ, at a standard deviation of σ_B = 2.86kΩ. With the samples being irradiated with a mean neutron flux density of 11.25 x 10^{11}ncm^{-2} for an average time of 2.25 hours, the electrical impedance of the samples have been lowered to a mean impedance of = 281.22kΩ, at a standard deviation of σ_A = 5.42kΩ. A difference in sample means of about 14.69kΩ.

4.6 Error Analysis

To err is human; to describe the error properly is sublime. The standard deviation of the distribution of estimated standard deviations is the error in each value of the estimated standard deviation. Errors of precision are combined in quadrature. Thus the standard error involved in the measurements made is given as:

$$S.E. = \sqrt{\frac{\sigma_B^2}{n} + \frac{\sigma_A^2}{n}}$$

$$S.E. = \sqrt{\frac{2.86^2}{10} + \frac{5.42^2}{10}}$$

$$\therefore S.E. = 1.94 \text{ k}\Omega.$$

Since the estimated standard deviation is the error in each individual measurement, the above formula is the error in the error! The estimated standard deviation is larger than the reading error (0.5% for the GM counter and ± 1.50Ω for HP Agilent 4194A Impedance Gain/Phase Analyzer); it will therefore be the error in the value of each of the data points.

4.7 Statistical (or Hypothetical) Test

The significance of this difference in sample means can be ascertained by the employment of the statistical t test. The level of significance appropriate for a quantitative data of this kind is $\alpha = 0.05$. The degrees of freedom, d.f. = $n - 1 = 10 - 1 = 9$. The hypothesis for the study was stated as follows:

$H_0 : \mu_A \geq 295.91$ kΩ, and $H_1 : \mu_A < 295.91$ kΩ. (NB: $\mu_B = 295.91$ kΩ).

At $\alpha = 0.05$ and d.f. = 9, the critical t value is -1.83 (read from statistical t table) (Figure 4.5).

The calculated or test value for t, is given as

$$t = \frac{\bar{X} - \mu}{s_X/\sqrt{n}} = \frac{\mu_A - \mu_B}{\sigma_A/\sqrt{n}} = \frac{281.22 - 295.91}{5.416/\sqrt{10}}$$

$$= -8.58.$$

The null hypothesis, $H_0 : \mu_A \geq 295.91$ kΩ, is rejected since $-8.58 < -1.83$. Thus the alternate hypothesis, $H_1 : \mu_A < 295.91$ kΩ is not rejected. The reduction in the mean value of the impedance of the asbestos samples is therefore significant; and it was mainly due to the irradiation of the samples with neutrons, and not due to some other unknown factors.

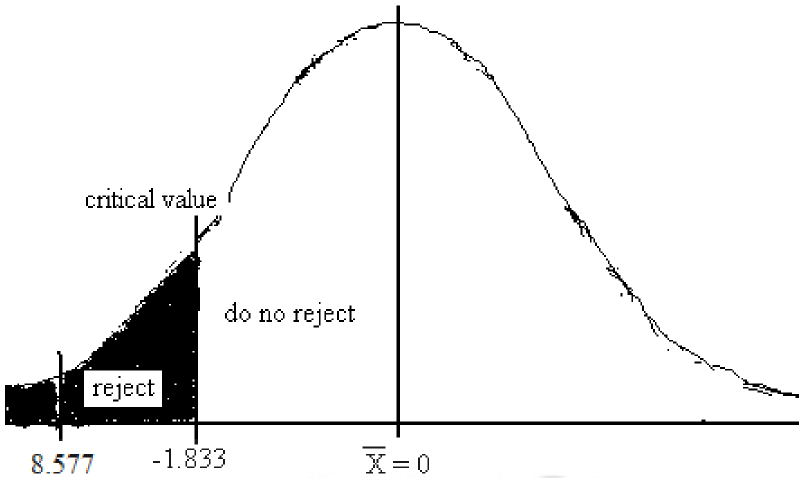

Figure 4.5: The Critical and the Test values of t for the Null Hypothesis.

4.8 Summary

For non-tissue matter like asbestos, several factors like age, temperature and pressure may affect its impedance. But the scope of the project will not permit such a detailed study. The study has therefore been restricted to investigating the effect that neutron irradiation will have on the electrical impedance of the asbestos. By determining the mean electrical impedance of the asbestos samples before and after they have been irradiated with neutron flux, it has been found that the mean electrical impedance of the samples have been lowered by a mean difference of (14.69 ± 1.94) kΩ.

At a significance level of α = 0.05 (i.e. 95% confidence interval), the t test indicates that the difference in the sample means is significant. Thus, irradiating an asbestos sample with neutrons will lead to a lowering of its electrical impedance.

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The study is an experimental research. Ten pairs of asbestos pieces cut from an old asbestos ceiling sheet were used. The electrical impedances of the pairs were measured and the mean value calculated for each pair. They were then irradiated with neutron flux of 5.0×10^{11} $ncm^{-1}s^{-1}$ at increasing time intervals. The electrical impedances were measured the second time and the mean value calculated for each pair. The two mean values were then compared.

A summary of the findings of the research are presented under this chapter. Valid conclusions that could be drawn from the findings of the study and some recommendations for implementation and for further research are stated.

5.2 Summary of Findings

The experiment that was performed yielded the following findings:

1. The mean electrical impedance of the samples after they were irradiated decreased, and the difference in the two mean values was found to be 14.96 ± 1.94 kΩ. A t-test of difference of sample means shows that the difference is significant; and the difference was due mainly to the neutron irradiation of the samples.
2. The average electrical impedances of sample pair ‘00’ (even though was not irradiated) were found also to decrease. Sample pair ‘00’ was stored in the same box with the irradiated samples. It might have therefore absorbed free electrons released by the irradiated samples that might have undergone beta decay after being irradiated by the neutrons.

3. The average electrical impedance of sample pair 'X' (which was not irradiated and also isolated from the other samples) was found to be relatively the same during the period of the research.

4. It was found that AIAI and NFD were related by the linear expression, $Z = 287.4 - 0.557\Phi$ (i.e., AIAI = 287.4 – 0.557NFD). The negative gradient indicates that as NDF, and for that matter, as the duration of exposure of the samples to the neutron flux increases the electrical impedance of the samples decreases.

5.3 Conclusion

The electrical impedance of a material depends on many factors, which include the composition of the material, the temperature of the material, the cross section area of the material, the time interval between the first and the second electrical impedance measurements, the accuracy of the machines used in the electrical impedance measurement as well as the level of radiation absorbed by the material. With these concomitant variables or covariates controlled, asbestos with a mean electrical impedance of μ_B = 295.91kΩ irradiated with a mean neutron flux density of 11.25 x 10^{11}ncm^{-2} for an average time of 2.25 hours, the electrical impedance was lowered to a mean electrical impedance of = 281.22kΩ. A difference in sample means of electrical impedance of about 14.26 ± 1.94kΩ.

Thus within the limits of experimental error, the effect that neutron irradiation have on the electrical impedance of the asbestos is that, it reduces it. This confirms the research hypothesis that was proposed at the beginning of the study.

This conclusion could be extended to all categories of asbestos in general. It could also be adduced to other ceramic materials, but definitely not to all non-tissue matter. Since the study was done with neutron irradiation, one may not be very justified in concluding that all kinds of radiations in the air will yield the same effect.

5.4 Implication of Findings

The finding that by irradiating asbestos with neutrons the electrical impedance of the asbestos will reduce, has several implications to scientists and engineers.

1. With time asbestos materials in an environment where there are neutrons in the air will conduct electricity since the electrical impedance will reduce.
2. The electrical insulating property of asbestos can not be fixed under all situations and places. It might only be fixed when the neutron flux density is zero considering the linear relation that exists between electrical impedance of asbestos and neutron flux density found in the study. The study did not disclose anything about the effect of other radiations on the electrical impedance of asbestos. But the knowledge of photoelectric effect indicates that gamma rays of a certain appropriate frequency will cause substances to emit free electrons into the system. NB: The electrical impedance of sample pair X was reduced by 0.03kΩ even without being irradiated with neutrons.
3. A system that has been irradiated with appreciable neutron flux will become ionised; an example is the plasma in a nuclear reactor core.

The finding that sample pair '00' that was not irradiated but became reduced in electrical impedance as a result of being stored in the same box with the irradiated samples implies that:

4. People and materials near a neutron flux region will be exposed to and also absorb beta particles.

5. Materials that are kept close with other substances that are irradiated with neutrons (and possibly other radiations) will have their properties (especially electrical impedance) affected. By the relation $Z = 287.4 – 0.557\Phi$, if the same asbestos was used in a typical spallation reactor with a neutron flux density of about $10^{15}ncm^{-2}s^{-1}$, its impedance would be reduced to – 5282.6kΩ (i.e., 287.4 – 0.557 x 10^4kΩ; NB: NFD is in $10^{11}ncm^{-2}s^{-1}$) within the 2.25 hours. The insulation will break down; and it will conduct current heavily.

6. John D. Gabbe's study on 'Some Measurements of Atmosphere Neutrons', recalculated the corrected neutron production rates to be 2.1 ± 0.4 $ncm^{-2}s^{-1}$ and 0.9 ± 0.4 $ncm^{-2}s^{-1}$ at $54^o\ 36^1$ and $30^o\ 24^1$ north of the geomagnetic latitude respectively using recent values for the various neutron cross sections.[28] The air in the atmosphere (which consist of gas molecules, water vapour and dust particles) always interact with these atmospheric neutrons. Even though this value looks insignificant, yet with time this could make the air electrically charged with its attendant problems.

5.5 Recommendations

Adducing from the implications of the findings of the study, the following recommendations can be made.

1. Asbestos, wherever it is used for the sake of its electrical impedance, must be regularly examined to ensure that they have not outlived their usefulness.
2. The use of asbestos as insulator of electricity ought to be reviewed. Substitute materials whose impedance remains more stable over a longer period in the midst of high and prolonged neutron irradiation should be substituted for asbestos.

3. Infrastructure must be regularly rewired and electrical insulating materials regularly changed, to avoid leakage of electricity that can lead to other disasters like electrical shocks and electrical fires.
4. The walls and the implements in the core of the reactor must be made of very poorly conducting materials; and should be regularly checked and replaced.
5. Facilities and people near and around a nuclear reactor plant should be regularly examined to know their flux level of beta particles and their electrical impedance.
6. The use of irradiation in agric and in business should be carefully monitored so that people handling irradiated substances and materials stored with irradiated substances are not adversely affected.
7. Infrastructure and machines must be provided with mechanisms that will neutralize charged air that fall on them. For instance, the lightening conductor must be used on every building not only to neutralize charged clouds in the rainy seasons, but to neutralize charged air in the atmosphere at all seasons.

5.6 Suggestions for Further Research

A study of this kind brings about many interesting questions. The following topics are therefore suggested for further investigation.

1. The effect of neutron irradiation on the electrical impedance of plastic.
2. The effect of gamma irradiation on the electrical impedance of cement brick.
3. The effect of gamma irradiation on the electrical impedance of plastic.
4. The effect of alpha particles irradiation on the electrical impedance of cement brick.
5. The effect of alpha particles irradiation on the electrical impedance of plastic.

6. The effect of neutron irradiation on the plasticity of plastic.
7. The effect of neutron irradiation on the specific heat capacity of cement brick.
8. The effect of gamma irradiation on the bulk modulus of cement brick.
9. The effect of gamma irradiation on the plasticity of plastic.
10. The effect of alpha particles irradiation on the specific heat capacity of clay.
11. The effect of alpha particles irradiation on the plasticity of plastic.

Similar investigation could be conducted on glass and wood. These and many more topics especially in relation to the interaction between matter and ionising radiations could be investigated.

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