Chapter One

General Introduction

1.1 Introduction

The science and clinical practice in nuclear medicine involve administration of trace amount of compounds labeled with radioactivity (radionuclides) that are used to provide diagnostic information in a wide range of disease states. Although radionuclides, also have some therapeutic uses. In its most basic form, a nuclear medicine study involves injecting a compound which labeled with agama - ray – emitting or positron – emitting radio nuclides into the body. The radio nuclides compound is called a radiopharmaceutical, or more commonly, a tracer or radiotracer. When the radionuclides decays, gamma ray are emitted. The energy of these gamma rays is such that a significant number can exit the body without being scattered or attenuated. An external position sensitive gamma ray camera can detect the gamma rays and form an image of distribution of the radionuclide (and hence the compound it was attached to and labeled products of reactions of the compound) throughout the body.(Cherry et al., 2012)

There are two main types of radiation of interest for imaging in nuclear medicine: γ ray emission from excited nuclei, and annihilation (or coincidence) radiation (γ) arising after positron emission from proton-rich nuclei. Gamma photons are detected with a gamma camera as either planar (2-d) images or tomographically in 3-d using single photon emission computed tomography (SPECT). The annihilation photons from positron

emission are detected using a positron emission tomography (PET) camera. The most recent major development in this field is the combination of gamma cameras or PET cameras with high resolution structural imaging devices, either X ray computed tomography (CT) scanners or, increasingly, magnetic resonance imaging (MRI) scanners, in a single image device. The combined PET/CT (or PET/MRI) scanner represents one of the most sophisticated and powerful ways to visualize normal and altered physiology in the body. The use of specific radiotracers called radiopharmaceuticals for imaging organ function and disease states is a unique capability of nuclear medicine. Unlike other imaging modalities such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasonography (US), nuclear medicine procedures are capable of mapping physiological function and metabolic activity and thereby giving more specific information about the organ function and dysfunction. The mapping of the radiopharmaceutical distribution in vivo provides images of functional morphology of organs in a non-invasive manner and plays an important role in the diagnosis of many common diseases associated with the malfunctioning of organs in the body as well as in the detection of certain type of cancers. The widespread utilization and growing demands for these techniques are directly attributable to the development and availability of a vast range of specific radiopharmaceuticals (Mattsson and Hoeschen, 2012).

Diagnostic importance of Nuclear Medicine examinations is outstanding, so the increase of examination frequency is justified. According to the International Commission on Radiological Protection (ICRP) dose limits should not be applied for medical exposures either diagnostic or therapy, because patients have direct benefit from the exposure. However according

to the basic principles of radiation protection the medical diagnostic procedures should be optimized and unjustified exposures should be minimized Nuclear Medicine procedures give patients more radiation dose than other traditional imaging modalities. Patients are exposed to more dose which may result in unintended health effects healthcare providers need to be able to estimate and track the dose these patients Receive from their Nuclear Medicine scan.(Bailey et al., 2014).

Bone scintigraphy or bone scan is one of the common procedures in routine nuclear medicine. The study is relatively simple, no patient preparation is required, and the imaging procedure is well standardized throughout diagnostic imaging departments. Modern equipment has greatly enhanced the ease of operation and permits imaging in planar, tomographic and whole body mode. Bone scintigraphy is an extremely sensitive procedure for evaluating a variety of skeletal disorders, and can also be applied for certain soft tissue abnormalities such as calcifications, hematoma, and contusion. The main indications for referral are screening of patients with malignancy, trauma, orthopedic problems, sports injuries, endocrine and rheumatologic disorders. Bone is a specialized form of connective tissue, with hardness as its characterizing feature. Gamma cameras have been optimized for 99mTc, and a high dose activity can be administered. These developments have led to the present important place of bone scintigraphy in clinical practice(Baert, 2006).

Radiation dose of bone scan According to ICRP-53 (International Commission on Radiological Protection 1987), the effective dose equivalent (EDE) for a routine whole body bone scan with 99mTc-MDP is 0.008 mSv/MBq, amounting to 5.9 mSv for a standard dose of 740 MBq (20 mCi).

The ICRP calculations assume an average voiding frequency of every 4 h (1), increasing the radiation dose. As mentioned earlier, the radiation burden can be decreased significantly by drinking ample fluids and voiding frequently, increasing the elimination of tracer from the body (Baert, 2006) . Evaluation of the bone marrow absorbed dose is important in diagnostic nuclear medicine as it is a significant contributor to the effective dose and should be accurately known. bone itself is sensitive to radiation, although this is of concern at low absorbed dose level where the stochastic risk of radiation induced exists (McParland, 2010).

1.2 Problem of the Study:

Due to use Nuclear Medicine scan, scanning patients are exposed to more doses which may result in unintended health effects, to avoid unnecessary of high dose to the patient need to estimate the effective dose for patients during bone scan.

1.3 Objectives of the study:

1.3.1 General Objectives:

To estimation effective dose and organ dose for adult patients in nuclear medicine during bone scan by TCm99-MDP using RADAR software and Dosisrad software's, professional computer programmes.

1.3.2 Specific Objectives:

• To estimate patients Effective dose (E)

• To estimate patients Organ equivalent dose (H_T)

•To compare between Dosisrad and RADAR softwares of effective dose calculated with both

• To compare average ED calculated with different values was reported of different countries and world commissions

1.4 Thesis outlines

This study consist of five chapters. Chapter one is an introduction, which include introduction, the problem of the study, objectives of the study and outline of the study. Chapter two including theoretical background and literature reviews concerning the previous studies. Chapter three deals with materials and methods used to acquire the data in this study. Chapter four deal with (result) data presentation. Chapter five include discussion of the result, conclusion and recommendations

Chapter Two

Theoretical Background

2.1. Importance of nuclear medicine

Nuclear medicine is a medical specialty using radioisotopes as tracers to diagnose diseases or for therapy. These tracers are usually attached to chemical compounds that are attracted to organs of interest such as bones or thyroid gland. After administration into the body, tracers emit characteristic radiations. Special electronic instruments, such as scintillation detector or a gamma camera, displays the recorded emissions as images. The images yield information about the anatomy or the functional state of the organ being imaged. In clinical applications of nuclear medicine, the amount of administered activity is low such that its corresponding absorbed dose to imaged and non-imaged tissues are typically very low and thus stochastic effect are outweighed by the diagnostic benefit of the imaging process. The role of internal dosimetry in diagnostic nuclear medicine is thus to provide the basis for stochastic risk quantification. Once this risk is quantified, it may be used to optimize the amount of administered activity in order to maximize image quality while minimizing patient risk. This optimization is considered, and always evaluated for any imaging procedure. Accurate dosimetry of diagnostic procedures is important for making judgments on the diagnostic benefits to the patient compared to the associated radiation risks. Dosimetry of diagnostic radiopharmaceuticals is therefore primarily concerned with the dosimetry of a total population or group .Image quantification in nuclear medicine is used, among other options, to estimate

activity in human subjects for the calculation of radiation dose (Bambara et al., 2015).

2.2 Diagnostic Nuclear Medicine

Medical internal radiation dosimetry is the discipline of determining the absorbed radiation doses received by an individual as a consequence of the deliberate or accidental intake of radioactive substances. Diagnostic nuclear medicine provides functional and physiological information of the patient through the in vivo imaging of photons emitted by a radionuclide or following the annihilation in the case of a positron-emitting radionuclide. Within the context of optimization, it is intended that the amount of radioactive substance administered to the patient be limited to that required for obtaining an image of the necessary diagnostic quality whilst minimizing the radiation dose burden borne by the patient. Accurate nuclear medicine radiation dosimetry is dependent upon not only the detailed knowledge of radiation matter interactions but also of the highly variable and far less-predictable bio kinetics of a radioactive substance in the human body and the broadly-estimated intrinsic radiosensitivities of tissues and organs. absorbed dose and patient risk, has long been followed in all aspects of and nuclear medicine. In particular, the reduction of patient radiation dose in diagnostic nuclear medicine can be achieved through a variety of means (McParland, 2010).

The second important use of radiation for imaging and diagnosis is in nuclear medicine .This involves the administration of radionuclides to patients, by injection, inhalation or ingestion, broadly as a biological tracer technique to study organ or tissue function. Diagnostic nuclear medicine is more about physiology and pathology than anatomy. The techniques hinge

on incorporating a suitable radionuclide into a pharmaceutical appropriate to the nature of the investigation. In practice a wide range of pharmaceuticals are used, incorporating more than 20 radionuclides that meet the necessary requirements for effective and efficient imaging, although 99mTc forms the basis for over 80% of all radiopharmaceuticals. Uptake of the radiopharmaceutical in particular organs, such as the thyroid, can be measured with a simple radiation detector, whereas imaging is carried out using a rectilinear scanner or, more commonly, a large field of view gamma camera. In addition to conventional planar imaging, techniques have also been developed to allow emission tomography which, rather like X ray CT, provides cross-sectional information. These techniques include single photon emission computed tomography (SPECT) or the specialized technique of positron emission tomography (PET), which uses short lived biologically active radionuclides. Diagnostic nuclear medicine has applications across a wide range of medical disciplines, with bone scans for metastases being the most common procedure on a global scale, followed by thyroid scans and cardiovascular scans.(IAEA, 2001).

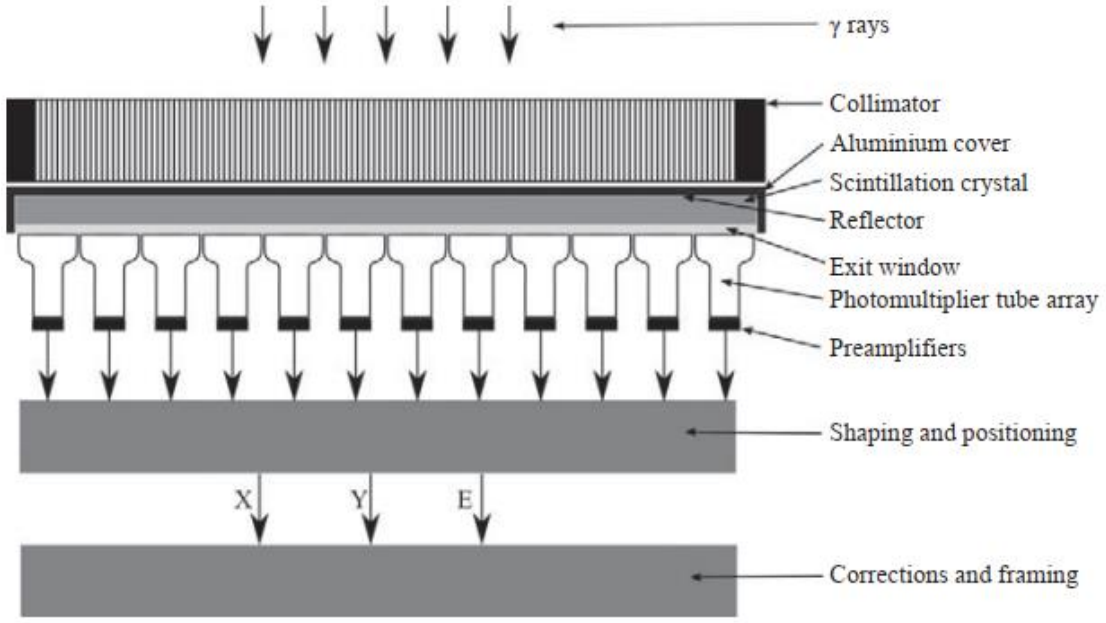
2.3 The Gamma Camera System

Gamma Camera is a major imaging device used in Nuclear Medicine. It is a diagnostic instrument which is used to image the radiation from a radiotracer inserted into patient's body. It scans the radiation area of the radiotracer and produces an image. The main purpose of Gamma Camera is to identify cancer tissues, proper abnormalities and other internal problems inside a patient's body. In the 1950s, Hal Anger conducted studies on medical imaging and from 1952 to 1958; he gradually developed the scintillation camera, also known as the Anger camera. After developing

gamma camera we get multiple gamma camera which generate a three dimensional image. Single photon emission computed tomography (SPECT) and positron emission tomography (PET) obeys this technology (Hasan et al., 2017).

The gamma camera is the principal instrument for imaging in nuclear medicine. As can be, it consists of a large detector in front of which the patient is positioned. Gamma cameras with more than one detector are now common, allowing a higher throughput of patients by acquiring two or more view simultaneously. Every aspect of the modern gamma camera is under computer control, allowing the operator to select the study acquisition time, or the number of counts to be acquired, to set the pulse height analyzers to reject scattered radiation, control the detector and patient bed positions for SPECT and whole body procedures, and display the image. All gamma camera manufactures sell associated computers and software to process and display the acquired images. The type of computer and the operating system upon which the software functions has, in the past, varied between manufacturers. This has led to a number of problems, which has hindered the transfer of data between systems. However, in recent years, driven by the demand for onscreen reporting of images by clinicians and the need to transfer data to picture archiving and communications systems (PACS), these problems have, in part, been overcome. The solution has been to develop an industry standard data format (DICOM) which, when used with the correct software, will allow the free movement of data between imaging systems.(Sharp et al., 2005)

FIG. 2.1 Schematic diagram showing the major components of a gamma camera



2.4 Mode of Operation of the Gamma Camera

The gamma camera is made up of many parts, each part performs as a specific function. The basic components of gamma camera are collimator, sodium iodide (NaI) crystal, and photomultiplier tubes (PMT) and position logic circuit. The basic principles of a camera works are the image of the distribution of the gamma-ray-emitting radiopharmaceutical is produced in the scintillation crystal by a collimator. The gamma rays, which are not visible to the eye, are converted into flashes of light by the scintillation crystal. This light is, in turn, transformed into electronic signals by an array of photomultiplier tubes (PMT) viewing the rear face of the crystal. After processing, the outputs from the PMTs are converted into three signals, two of which (X and Y) give the spatial location of the scintillation while the third (Z) represents the energy deposited in the crystal by the gamma ray. To improve their quality these signals then pass through correction circuits. The

Z signal goes to a pulse height analyzer (PHA), which tests whether the energy of the gamma ray is within the range of values expected for the particular radionuclide being imaged. If the Z signal has an acceptable value, then a signal is sent instructing the display to record that there has been a gamma ray detected, the position being determined by the X and Y signals (Sharp et al., 2005).

2.5 PERMISSIBLE DOSES IN NUCLEAR MEDICINE

No official upper limits have been placed on the organ dose or the whole body dose arising from the administration of radionuclides. It is the feeling of most investigators that no firm rule should be laid down, but that the potential risks of any procedure should be evaluated in terms of the potential benefits and that this consideration should override all others. For example, if the potential risk of a brain tumor, with death in 6 months if not detected and treated, is weighed against the potential radiation risk of a brain scan, then a very large dose of radiation becomes diagnostically acceptable. The important principle that no more radiation be given than is absolutely necessary to establish the diagnosis has an important corollary. Enough radiation should be used to make an accurate diagnosis. A serious error in judgment would be perpetrated if, after weighing the risks and benefits, one decided to perform a brain scan using too small a dose of radioactivity.no firm permissible dose should be established for a diagnostic procedure. On the other hand, this does not mean that a clinician should be unconcerned with the absorbed dose. He should know the approximate absorbed dose for each of the procedures used. The use of short-lived isotopes such as Tc-99m provide an enormous advantage, since large amounts of these nuclides may be used without delivering large absorbed doses to the organ (Johns, 1983).

2.6 Patient dosimetery in nuclear medicine

2.6.1 Adjusting the activity for differences in patient size and weight

Protocols used in nuclear medicine practices should specify the usual activity of the radiopharmaceutical to be administered to a standard patient. In most western countries, the standard patient is taken to be one whose weight is in the range 70–80 kg. However, many patients fall outside of this range. If a fixed activity is used for all patients, this will lead to an unnecessarily high radiation exposure to an underweight patient and may lead to images of unacceptable quality or very long imaging times in obese patients. There have been various approaches to determining the activity to be administered. These are usually designed to provide a constant count density in the image to maintain image quality or to provide a constant effective dose to the patient. For example, it has been shown that for myocardial perfusion scans using 99mTc-tetrofosmin, the activity should be increased by 150% for a 110 kg patient and by 200% for a 140 kg patient in order to maintain image quality without increasing imaging time. it has been shown, using the radiation dose tables provided in international commission on radiological Protection (ICRP) publications 53, 80 and 106 [9.6–9.8], that the effective dose (msv/Mbq) can be expressed as a simple power function of body weight. Scaling factors for the activity, to give a constant effective dose can, therefore, be derived from the expression $(W/70)a$, where W represents the weight of the person and the power factor a is specific for the radiopharmaceutical. again, using 99mTc-tetrofosmin as an example, a is found to be –0.834. Although the dosimetry models are only available up to 70 kg, this power function can be extrapolated to derive scaling factors for patients whose weight exceeds 70 kg using this approach, the activity should

be increased by 146% for a 110 kg patient and by 178% for a 140 kg patient. This approach is useful, but should be used with caution. The extrapolated activity would lead to comparable organ and tissue doses for a patient of large body build but not for a patient of similar weight due to large body fat deposits as the biodistribution of the radiopharmaceutical would not be the same in these two cases(Bailey et al., 2014).

The term ‘typical dose’, as used in the BSS paragraph 3.168, refers to the average or median dose or activity for a particular size of patients. Patient size has a large influence on doses, so some selection or grouping of patients is required. Such groupings include ‘average adult’, often based around an average weight of 70 kg with a range of ± 20 kg. The nuclear medicine facility should adopt patient size groupings that correspond with the groupings used in their country or state for DRLs. The sample size used for each patient grouping and radiological procedure should be of sufficient size to assure confidence in the determination of the mean dose. Patient dosimetry to determine typical doses in diagnostic nuclear medicine should be carried out in conjunction with an assessment of the diagnostic image quality. Exposure alone is not meaningful if it does not correspond to images that are sufficient for an accurate diagnosis. The results of the surveys used to determine typical doses at the nuclear medicine facility should be used as part of the facility’s on-going review of the implementation of optimization of protection, and additionally will be used for comparison with established DRLs. Sometimes patient dosimetry in diagnostic nuclear medicine procedures may be required for specific individual patients. Reasons might include an unintended or accidental medical exposure where an estimation of patient doses is required as part of the investigation and. There are several

indirect and direct methods to estimate patient dose in diagnostic nuclear medicine procedures (IAEA, 2014) (20)

2.7 99Mo 99mTc Generator

The 99Mo radionuclide has a half-life of 66 h and decays by b emission; 87% of its decay goes ultimately to the metastable state 99mTc and the remaining 13% to the ground state 99Tc. It has photon transitions of 740 and 780 Kev. The radionuclide 99mTc has a half-life of 6 h and decays to 99Tc by isomeric transition of 140 Kev. Approximately 10% of these transitions are via internal conversion. The ground state 99Tc has a half-life of 2.1* 105 years and decays to stable 99Ru by b emission. Because the half-lives of 99Mo and 99mTc differ by a factor of about 11, these two radionuclides lend themselves to the construction of a useful generator. The extreme usefulness of this generator is due to the excellent radiation characteristics of 99mTc, namely its 6-h half-life, little electron emission, and a high yield of 140-keV g rays (90%), which are nearly ideal for the current generation of imaging devices in nuclear medicine. The 99Mo–99mTc or "Moly" generator is constructed with alumina (Al2O3) loaded in a plastic or glass column. The amount of alumina used is of the order of 5–10 g, depending on the total activity of 99Mo. The 99Mo radioactivity is adsorbed on alumina in the chemical form Mo (O2)4 (molybdate) and in various amounts. The column is thoroughly washed with 0.9% NaCl solution to remove any undesirable activity. Currently, all generators are made with fission-produced 99Mo. The generator columns are shielded with lead for radiation protection. Some commercial firms use depleted uranium in lieu of lead for shielding high 99Mo activity generators (8.3–16.6 Ci or 307–614 GBq) because 238U has higher Z and therefore attenuates g rays more efficiently

(depleted uranium is natural uranium from which 235U has been removed, leaving only 238U). After adsorption of 99Mo on alumina, 99mTc grows by the decay of 99Mo according to until its maximum activity is reached after approximately four half-lives of 99mTc. At equilibrium and thereafter, the 99mTc radioactivity follows the half-life of 99Mo.The 99mTc radionuclide is eluted as sodium pertechnetate (Na99mTcO4) with a 0.9% NaCl solution (saline without any additivies). After elution, the 99mTc radioactivity starts to grow again in the column. Elution may be carried out, if needed, even before equilibrium is reached The amount of 99mTc activity obtained in this case will depend on the time elapsed between the previous and present elusions (Saha, 2010).

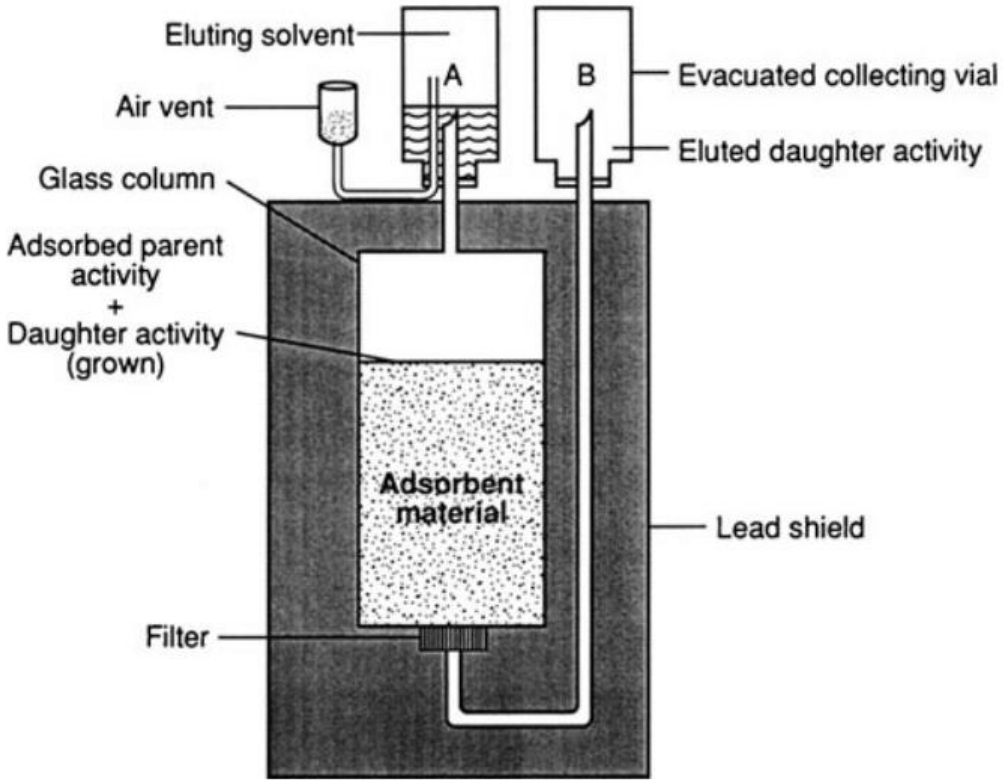


FIGURE 2.2. Typical generator system. The daughter activity grown by the decay of the parent is separated chemically from the parent. The eluent in

vial A is drawn through the column and the daughter nuclide is collected in vial B under vacuum (Saha and Saha, 2004).

2.8 Radiopharmaceuticals (Tc 99m MDP)

Radiopharmaceuticals are radioactive agents that have been used extensively in the field of nuclear medicine as noninvasive diagnostic imaging agents to provide both functional and structural information about organs and diseased tissues. They may be given to the patient in several ways, e.g. orally, parenterally, or placed into the eye or the bladder. A diagnostic radiopharmaceutical is a drug that is intended for use in the diagnosis or monitoring of a disease or a manifestation of a disease in humans and that exhibits spontaneous disintegration of unstable nuclei with the emission of nuclear particles, photons, any nonradioactive reagent kit or nuclide generator that is intended to be used in the preparation of such a drug. The nonradionuclidic portion of the diagnostic radiopharmaceutical is often an organic molecule such as a carbohydrate, lipid, nucleic acid, peptide, small protein, or antibody. Radiopharmaceuticals are used to help diagnose medical problems, only small amounts are given to the patient. The radiopharmaceutical then passes through or is taken up by an organ of the body (organ selection depends on which radiopharmaceutical is used and how it is administered). The radioactivity is then detected, and images produced, by special imaging equipment. These images allow the nuclear medicine physician to study how the organ is working and to detect cancer or tumors that may be present in the organ. Some radiopharmaceuticals are used in larger amounts to treat certain kinds of cancer and other diseases. Using cameras designed to detect gamma photons leaving the patient's body, the nuclear medicine physician directly observes regional radiotracer distribution and kinetics. This allows the clinician to noninvasively evaluate

those aspects of tissue function involved in the body's handling of the administered agent. for radionuclide imaging include conventional planar and tomographic (SPECT) methods for detection of gamma photons (typically in the range of 60–400 Kev), and imaging by PET, where one detects the 511 Kev photons produced by positron–electron annihilation (TÜRKER and ÖZER, 2004).

Tc 99m MDP bone scintiscanning is widely regarded as the most cost-effective and available whole-body screening test for the assessment of bone metastases. Tc 99m diphosphonates most commonly Tc 99m methylene diphosphonate (MDP) is the most frequently used isotope. Bone scan (BS) was performed by the intravenous administration of technetium 99m methylene diphosphonate (MDP) at a dose of 20 mCi. Images were obtained on a dual head gamma camera. Bone phase images were taken approximately three hrs after injection of the radiotracer and the scan time is about 15 minutes for a whole body scan. Tc 99m MDP bone scan plays a pivotal role for detection of skeletal metastasis which is very essential to manage Ca lung patient. As bone scintigraphy is very cost effective in govt. nuclear medicine centre in comparison to other imaging modalities, so it can play a major role in detecting skeletal metastasis in ca lung patients in a developing country Tc 99m MDP Bone scintiscanning should be used as the preferred screening investigation because of its low cost, wide availability, usefulness in imaging the entire skeleton and high sensitivity(Afrin et al., 2016). Technetium-99m MDP It is amonoenergetic emitter of 140 Kev gamma rays with a physical half-life of6.02 hours and efficiently labels phosphonates or pyrophosphates, yielding 99mTc-MDP. These have a strong avidity for hydroxyapatite crystals in the mineral phase

of the bone, especially at sites where new bone is actively formed as in the physes of growing bones and fractures. The diphosphonate molecule is adsorbed onto the calcium of hydroxyapatite in bone. 99mTc-diphosphonates are rapidly distributed in the extracellular fluid space and approximately half of the injected dose is taken up by bone, with the unfixed portion excreted into the urine by glomerular filtration. The amount of radiopharmaceutical accumulated in bone at 1 hour after injection is 58% with MDP (IAEA, 2006).

2.9 Radioactivity

These unstable isotopes attempt to reach the stability curve by splitting into fragments, in a process called Fission, or by emitting particles and/or energy in the form of radiation This process is called Radioactivity (Maher and Contributors, 2006)**.** The phenomenon of spontaneous emission of such particles from the nucleus is called radioactivity, and the nuclides are called radionuclides. The change from the unstable nuclide (parent) to the more stable nuclide (daughter) is called radioactive decay or disintegration. During disintegration, there is emission of nuclear particles and release of energy. The process is spontaneous, and it is not possible to predict which radioactive atom will disintegrate first. For all practical purposes, the nucleus can be regarded as a combination of two fundamental particles: Neutrons and protons. These particles are together termed nucleons. The stability of a nucleus Depends on at least two different forces: the repulsive Coulomb force between any two or more protons and the strong attractive force between any two nucleons (nuclear forces). The nuclear forces are strong but effective over short distances, whereas the weaker coulomb forces are effective over longer distances. The stability of a nucleus depends on the

arrangement of its nucleons, particularly the ratio of the number of neutrons to the number of protons. An adequate number of neutrons is essential for stability. Among the many possible combinations of protons and neutrons, only around 260 nuclides are stable; the rest are unstable .It seems that there are favored neutron-to-proton ratios among the stable nuclides (Magdy, 2011).

The term of radioactive refers to the emission of particles and/or energy from unstable isotopes. Unstable isotopes for instance those that have too many protons to remain a stable entity are called radioactive isotopes - and called radioisotopes for short. The term radionuclide is also sometimes used(Maher and Contributors, 2006).

2.9.1 Radioactivity Units

The SI or metric unit of radioactivity is named after Henri Becquerel, in honour of his discovery of radioactivity, and is called the becquerel with the symbol Bq. The traditional unit of radioactivity is named after Marie Curie and is called the curie, with the symbol Ci(Maher and Contributors, 2006).

2.9.2 Mods of radioactivity decay

1. Alpha decay (elements above Pb in the periodic table e.g. decay series)

$$^{226}_{88}Ra \xrightarrow{\alpha} {}^{222}_{86}Rn + {}^{4}_{2}He \qquad n \xrightarrow{\alpha} P^{+} + e^{-} + \bar{\nu} \quad \ldots\ldots (1)$$

2. Beta decay

a) Isotopes with an excess of neutrons: emit $\beta -$ particles (electrons).

$$n^{+} \xrightarrow{\beta-} P^{+} + e^{-} + \bar{\nu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

b) Isotopes with a deficiency of neutrons: emit β^+ particles (positrons)

$$P^+ \xrightarrow{\beta^+} n + e^+ + \nu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3$$

3. Electron capture

$$P^+ e^- \xrightarrow{EC} n + \nu \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The nucleus captures an electron from an orbital shell, then an electron from a higher energy level fill the vacancy resulting in *characteristic X-ray* photons or Auger electrons.(Keresztes et al., 2015)

2.10 Production of Radionuclides

2.10.1 Cyclotron Produced Radionuclides

In a cyclotron, charged particles such as protons, deuterons, a particles, 3He particles, and so forth are accelerated in circular paths in so-called dees A and B under vacuum by means of an electromagnetic field.These accelerated particles can possess a few kilo electron volts (Kev) to several billion electron volts (BeV) of energy depending on the design and type of the cyclotron. Cyclotron-produced radionuclides are usually neutron deficient and therefore decay by b+ emission or electron capture. Example of a simple cyclotron-produced radionuclide is 111In, which is produced by irradiating 111Cd with 12-MeV protons in a cyclotron. The nuclear reaction is written as follows

111Cd (p; n) 111In

Where 111Cd is the target, the proton p is the irradiating particle, the neutron n is the emitted particle, and 111In is the product radionuclide.(Saha and Saha, 2004)

2.10.2 Reactor Produced Radionuclides

A variety of radionuclides are produced in nuclear reactors. In the reactor, two types of interaction with thermal neutrons are of considerable importance in the production of various useful radionuclides: fission of heavy elements and neutron capture or (n, g) reaction. These two reactions are described below.

2.10.2.1 Fission or (n, f) Reaction

As already mentioned, fission is a breakup of a heavy nucleus into two fragments of approximately equal mass. When a target of heavy elements is inserted in the reactor core, heavy nuclei absorb thermal neutrons and undergo fission. Fissionable heavy elements are 235U, 239Pu, 237Np, 233U, 232Th, and many others having atomic numbers greater than 90. The fission radionuclides are normally carrier-free or NCA, and therefore isotopes of high specific activity are available from fission. The fission products are usually neutron rich and decay by b emission. Many clinically useful radionuclides such as 131I, 99Mo, 133Xe, and 137Cs are produced by fission of 235U.(Saha and Saha, 2004).

2.10.2.2 Neutron Capture or (n, g) Reaction

In neutron capture reaction, the target nucleus captures one thermal neutron and emits g rays to produce an isotope of the same element. The radionuclide so produced is therefore not carrier-free and its specific activity (described later) is relatively low. Since the target and the product nuclei belong to the same element, chemical separation is obviously unnecessary. Various useful radionuclides produced by this reaction are 131Te, 99Mo, 59Fe and many more. These radionuclides are often neutron rich and therefore decay by β – emission. Some examples of neutron capture reactions are 98Mo (n, g) 99Mo.

2.10.3 Generators Produced Radionuclides

A generator is constructed on the principle of the decay–growth relationship between a long-lived parent radionuclide and its short-lived daughter radionuclide Because there are differences in chemical properties, the daughter activity is eluted in a carrier-free The use of short-lived radionuclides has grown considerably, because larger dosages of these radionuclides can be administered to the patient with only minimal radiation dose and produce excellent image quality(Saha and Saha, 2004).

Radionuclide	Mode of production	Type of decay[a]	Principal photon emissions (keV)	Half-life
Imaging tests				
^{67}Ga	Cyclotron	EC	92, 182, 300, 390	78 h
^{123}I	Cyclotron	EC	160	13 h
^{131}I	Reactor	Beta	280, 360, 640	8 days
^{111}In	Cyclotron	EC	173, 247	2.8 days
^{113m}In	Generator	IT	391	100 min
^{81m}Kr	Generator	IT	191	13 s
^{99m}Tc	Generator	EC	140	6 h
^{201}Tl	Cyclotron	EC	68–80[b]	73.5 h
^{133}Xe	Reactor	Beta	81	5.3 days
Non-imaging tests				
^{14}C	Reactor	Beta	–	5760 years
^{51}Cr	Reactor	EC	323	27.8 days
^{54}Fe	Reactor	Beta	1100, 1300	45 days
^{42}K	Reactor	Beta	–	14.3 days

[a] EC, electron capture; IT, isometric transition.
[b] Characteristic X-rays.

Table 2.1 Characteristics of commonly used radionuclides (6)

2.11 QUALITY ASSURANCE AND QUALITY CONTROL IN NUCLEAR MEDICINE

It is now widely recognized that the attainment of high standards of efficiency and reliability in the practice of nuclear medicine, as in other specialities based on advanced technology, requires an appropriate quality

assurance programme. The concept of quality in the term "quality assurance" expresses the closeness with which the outcome of a given procedure approaches some ideal, free from all errors and artefacts. Quality assurance embraces all efforts made to this end. The term "quality control" is used in reference to the specific measures taken to ensure that one particular aspect of the procedure is satisfactory. A clear distinction between these terms should be made. Hence, quality assurance in nuclear medicine should cover all aspects of clinical practice. Specifically, quality control is necessary in the submission of requests for procedures; the preparation and dispensing of radiopharmaceuticals; the protection of patients, staff and the general public against radiation hazards and accidents caused by faulty equipment; the scheduling of patients; the setting-up, use and maintenance of electronic instruments; the methodology of the actual procedures; the analysis and interpretation of data; the reporting of results and, finally, the keeping of records. The present document deals with a single, albeit highly important, component of such a comprehensive programme, namely quality control of instrument (Agency, 1984).

2.12 Assay of Radioactivity for Clinical Use

The accurate assay of activity prior to administration is one of several important processes required to assure that patients receive the correct radiopharmaceutical dosage. Assuming that the treatment or diagnostic study is appropriate and the prescribed radiopharmaceutical is being administered via the prescribed route to the correct patient, other processes include the determination of the appropriate activity to be administered and the successful administration of that activity. Radionuclide or dose calibrators are the instruments most often employed to assay the activity of a

radioactive material prior to clinical use. The objective of the assay is to help assure that the patient receives the minimum absorbed dose compatible with obtaining a high-quality diagnostic image or with achieving a desired therapeutic outcome.(Medicine, 2012).

2.13 Dose calibrator

A dose calibrator, is used to measure the activities of doses of radiopharmaceuticals to be administered to patients. The U.S. Nuclear Regulatory Commission (NRC) and state regulatory agencies require that doses of x-ray- and gamma ray-emitting radiopharmaceuticals be measured with a dose calibrator. Most dose calibrators are well-type ionization chambers that are filled with argon (Z = 18) and pressurized to maximize sensitivity. Some less expensive dose calibrators instead use GM tubes near a chamber for the insertion of the dose. Most dose calibrators have shielding around their chambers to protect users from the radioactive material being assayed and to prevent nearby sources of radiation from affecting the measurements. A dose calibrator cannot directly measure activity. Instead, it measures the intensity of the radiation emitted by a dose of a radiopharmaceutical. The manufacturer of a dose calibrator determines calibration factors relating the intensity of the signal from the detector to activity for specific radionuelides commonly used in nuelear medicine. The user pushes a button or turns a dial on the dose calibrator to designate the radionuclide being measured, thereby specifying a calibration factor, and the dose calibrator displays the measured activity**.** Dose calibrators using ionization chambers are operated in current mode, thereby avoiding dead-time effects. They can accurately assay activities as large as 2 Ci. For the same reasons, they are relatively insensitive and cannot accurately assay activities less than about 1m /lCi. In general, the identification and

measurement of activities of radionuclides in samples containing multiple radionuclides is not possible. The measurement accuracy is affected by the position in the well of the doses being measured, so it is important that all measurements be made with the doses at the same position. Most dose calibrators have large wells, which reduces the effect of position on the measurement. Dose calibrators using large well-type ionization chambers are in general not significantly affected by changes in the sample volume or container for most radionuclides. However, the measured activities of certain radionuclides, especially those such as In-Ill, 1-123, 1-125, and Xe-133 that emit weak x-rays or gamma rays, are highly dependent on factors such as whether the container (i.e., syringe or vial) is glass or plastic and the thickness of the container's wall. There is currently no generally accepted solution to this problem. Some radiopharmaceutical manufacturers provide correction factors for these radio nuclides; these correction factors are specific to the radionuclide, the container, and the model of dose calibrator.(Bushberg and Boone, 2011).

The radionuclide activity dose calibrators are routinely used in nuclear medicine practices to quantify the radioactivity dose of the radiopharmaceuticals to be administered to the patients. According to the current standards and regulations for NM worldwide practices, including those adopted by the international atomic energy agency (1-5), and national regulations such as those promulgated by the United States N u c l e a r R e g u l a t o r y C o m m i s s i o n (U.S.NRC), the radioactivity of any radiopharmaceutical that contains a photon-emitting radionuclide must be measured by a dose calibrator prior to administration to patients or for human research purposes. Obviously, the administration of the prescribed amount of activity to the patient requires proper operation of the dose

calibrator, which shall be verified by implementing the required quality control tests on the instrument. Several quality control tests are necessary to ensure the proper operation of the dose calibrators, among which the tests for the linearity of the response, accuracy, precision, and physical functioning of the instrument are of more importance.(Zeinali, 2010).

FIGURE 2.3. A radionuclide dose calibrator, Biodex model Atomlab 500. (Photo courtesy of Biodex Medical Systems, Inc.) (Saha and Saha, 2004).

2.14 The Uncertainty Budget

The error or uncertainty associated with the dosage assay is just one contributor to the difference between the prescribed dosage and the administered dosage. The logistics and techniques of dosage delivery also influence the amount of activity administered. Two potential significant sources of uncertainty are (1) the difference between the dosage calibration time and dosage administration time and (2) the residual activity remaining in the vial or syringe, the needle, or other parts of the delivery system post administration. It is interesting to note that a number of the significant sources of uncertainty result in administered dosages that are less than the prescribed dosages. While the time to administration may lead to

administered dosages that are greater than the prescribed dosage (i.e., for administrations at times pre-calibration); for dosages prepared in-house (versus unit dosages obtained from commercial nuclear pharmacies), radioactive decay most often results in less activity being administered. The errors due to residual activity result in less activity being administered and the assay of syringe using a calibration setting obtained using glass-vial geometry yields an overestimate of the activity in the syringe.(Medicine, 2012).

2.15 Interaction of Photons with Matter

As they pass through matter, photons interact with atoms. The type of interaction is a function of the energy of the photons and the atomic number *(Z)* of elements composing the matter.

2.16 Types of Photon Interactions in Matter

In the practice of nuclear medicine, where gamma rays with energies between 50 Kev and 550 Kev are used, Compton scattering is the dominant type of interaction in materials with lower atomic numbers, such as human tissue *(Z* = 7.5*)*. The photoelectric effect is the dominant type of interaction in materials with higher atomic numbers, such as lead *(Z* = 82*)*. A third type of interaction of photons with matter, pair production, only occurs with very high photon energies (greater than 1020 Kev) and is therefore not important in clinical nuclear medicine.(Powsner and Powsner, 2008).

2.16.1Compton Scattering

In Compton scattering the incident photon transfers part of its energy to an outer shell or (essentially) “free "electron, ejecting it from the atom. Upon ejection this electron is called a Compton electron. The photon is scattered) at an angle that depends on the amount of energy transferred from the

photon to the electron. The scattering angle can range from nearly 0◦ to 180◦.

2.16.2 Photoelectric Effect

A gamma ray of low energy, or one that has lost most of its energy through Compton interactions, may transfer its remaining energy to an orbital (generally inner-shell) electron. This process is called the photoelectric effect and the ejected electron is called a photoelectron. This electron leaves the atom with an energy equal to the energy of the incident gamma ray diminished by the binding energy of the electron. An outer-shell electron then fills the inner-shell vacancy and the excess energy is emitted as an x-ray(Powsner and Powsner, 2008).

Ephotoelectron = Ephoton – Ebinding.

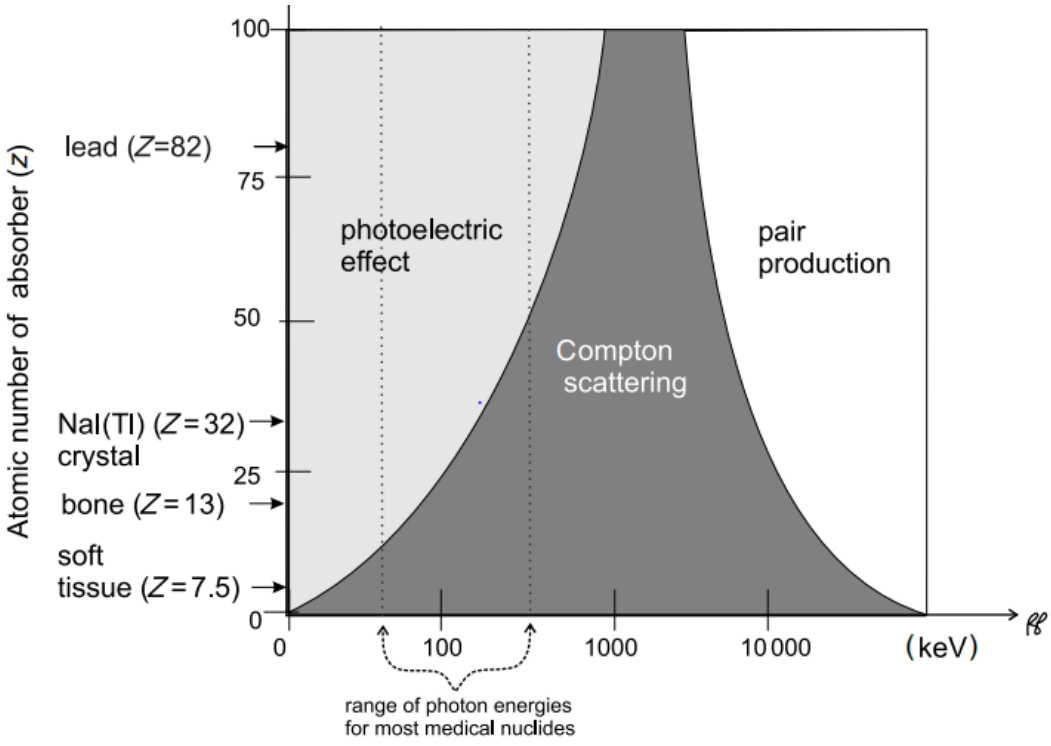


Figure 2-4 Predominant type of interaction for various combinations of incident photons and absorber atomic numbers.(Powsner and Powsner, 2008).

2.17 Linear Energy Transfer

The energy transferred to the tissue by ionizing radiation per unit tract length is called the LET.

• The LET is a function of the charge and the velocity of the ionizing radiation.

• The LET increases as the charge on the ionizing radiation increases and its velocity decreases.

• Alpha particles are slow and positively charged. Beta particles, on the other hand, are fast and negatively charged. Therefore, the LET of an alpha particle is higher than that of a beta particle.

• Lethal effects increase as the LET increases.

• The units of the LET are Kev/μm.

The potential harm to biological materials caused by their irradiation is directly proportional to the efficacy with which the radiation deposits energy in the material. Proton, neutron and alpha particles lose their energies over much shorter distances than X-rays and gamma rays with the same energy. Since high-LET radiation (particulate radiation) transfers more energy per unit length of material, the probability of causing DNA damage in a short period of time is high. Thus, a. dose of high-LET radiation is more destructive than the same dose of low-LET radiation (Beyzadeoglu et al., 2010).

2.18 Biological effects of radiation

Any biological effect of radiation, whether deleterious or being, strongly depends on the radiation dose. Generally more effects and more serious effects are produced by high than low doses. The exact relationship of the dose to effect produced depends on nature of the effect (Chandra and

Rahmim, 2017). The effects of radiation on tissues and organs can be classified into three groups: acute, subacute and chronic. *Acute effects*: changes that occur in the first 6 months. *Subacute effects*: changes that occur between 6 and 12 months. *Chronic effects*: changes that occur after 12 months. Carcinogenesis, genetic mutations and chromosomal aberrations occur the acute and subacute effects of radiation are known as deterministic effects (nonstochastic effects). The intensities of these effects are directly proportional to the dose. If the total body irradiation dose is >5 Gy, bone marrow suppression is observed, but this suppression is not observed for a dose of <5 Gy. The chronic effects of radiation are known as stochastic effects. These are statistically measurable effects (Beyzadeoglu et al., 2010).

Radiation-induced hereditary effects have been clearly demonstrable in animal experiments involving mice and fruit flies, but never in any human population, including the Japanese bomb survivors, medical populations, and populations affected by the Chernobyl disaster. As with cancer, there is a spontaneous rate of mutations that is ongoing in the human population, with no excess exposure to chemicals, radiation, or other mutagenic agents. In the most recent recommendations of the ICRP, the risk weighting factor has decreased substantially, perhaps reflecting the fact that more time has gone by and no significant effects have been demonstrated in human populations.(Stabin, 2007). Studies of animal survival following large doses of ionizing radiation have demonstrated a range of lethal doses that vary with the species and the irradiation conditions. (Hendee, 2003).

2.19 System of Protection in nuclear medicine procedures

In the 1990 Recommendations, the Commission gave principles of protection for exercise separately from interference status. The Commission continues to regard these principles as fundamental for the system of protection, and has now formulated a single set of principles that apply to planned, emergency, and existing exposure situations. In these Recommendations, the Commission also clarifies how the fundamental principles apply to radiation sources and to the individual, as well as how the source-related principles apply to all controllable situations. (Valentin, 2007)

2.19.1 Justification

No practice or source within practice should be authorized unless it produces sufficient benefits to the exposed individuals or society, to offset the radiation harm that it might cause. That is unless the practice is justified, taking into account social, economic and other relevant face. (Rehani et al., 2010).

2.19.2 Optimization

In relation to exposure from any particular source within practice, except for therapeutic medical exposures, protection and safety shall be optimized in order to keep the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures as low as reasonably achievable. Economic and social factors being taken into account, within the restriction that the doses to individuals delivered by the source shall be subjected to dose constraints. (Rehani et al., 2010).

2.19.3 Dose limitation

The normal exposure of individuals shall be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs or tissues, caused by the possible combination of exposures from authorized practices, the limit on effective dose represents the level above which the risk of stochastic effects due to radiation is considered to be unacceptable. (Valentin, 2007).

2.20 Quantities and units for Dosimetric and Protection

2.20.1 Absorbed Dose

Absorbed dose is a non-stochastic quantity applicable to both indirectly and directly ionizing radiations. For indirectly ionizing radiations, energy is imparted to matter in a two-step process. In the first step (resulting in kerma), the indirectly ionizing radiation transfers energy as kinetic energy to secondary charged particles. In the second step, these charged particles transfer some of their kinetic energy to the medium (resulting in absorbed dose) and lose some of their energy in the form of radiative losses (bremsstrahlung, annihilation in flight). The absorbed dose is related to the stochastic quantity energy imparted. The absorbed dose is defined as the mean energy **i**mparted by ionizing radiation to matter of mass ***m*** in a finite volume ***V*** by:

$$D = \frac{d\varepsilon}{dm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The energy imparted ε is the sum of all the energy entering the volume of interest minus all the energy leaving the volume, taking into account any mass–energy conversion within the volume. Pair production, for example, decreases the energy by 1.022 MeV, while electron–positron annihilation increases the energy by the same amount**.** That because electrons travel in the medium and deposit energy along their tracks, this absorption of energy does not take place at the same location as the transfer of energy described by kerma. The unit of absorbed dose is joule per kilogram (J/kg). The name for the unit of absorbed dose is the gray (Gy).(Podgorsak, 2005).

$$1 \text{ rad} = 100 \text{ erg/g} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$1 \text{ gray (Gy)} = 1 \text{ J/kg} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

$$1 \text{ Gy} = 100 \text{ rad} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The word *rad* was originally an acronym meaning "radiation absorbed dose." The rad is being replaced by the SI unit value, the gray (Gy), which is equal to 100 rad. Note that *rad* and *gray* are collective quantities: one does not need to place an "s" after them to indicate more than one (Stabin, 2008).

2.20.2 Equivalent Dose

The biological detriment (harm) to an organ depends not only on the physical average dose received by the organ but also on the pattern of the dose distribution that results from the radiation type and energy. For the same dose to the organ, **o**r neutron radiation will cause greater harm compared with gamma rays or electrons. This is because the ionization events produced by **a** neutron radiation will be much more closely spaced (densely ionizing radiations) and so there is a higher probability of irreversible damage to the chromosomes and less chance of tissue repair.

Consequently, the organ dose is multiplied by a radiation weighting factor ***w***R to account for the effectiveness of the given radiation in inducing health effects; the resulting quantity is called the equivalent dose ***H***T. The equivalent dose ***H***T is defined as**:**

$$\mathrm{HT} = D \times W_R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where D is the absorbed dose and W_R is the radiation weighting factor.

The SI unit of equivalent dose is J/kg and its name is the Sievert (Sv)

The organ dose is a measure of the energy absorption per unit mass averaged over the organ, while the equivalent dose is a measure of the consequent biological harm (detriment) to the organ or tissue.(Podgorsak, 2005)

Table 2.3: Radiation weighting factors in publication ICRP 60 and Q in publication ICRP 60.(Protection, 1990)

Type and energy range	**W_T**	**Q**
Photons (x-ray and gamma rays) all energies	1	1
Electron, muons, all energies	1	1
Neutrons < 10 Kev	5	-
Neutrons 10 Kev to 100 Kev	10	-
Neutrons > 100 Kev to 2MeV	20	-
Neutrons > 2 MeV to 20 MeV	10	-
Neutrons > 20 MeV	5	-
Protons > 20 MeV	5	1
Alpha particles fission- fragment heavy nuclei	20	20

2.20.3 Effective dose

The effective dose **E** is defined as the summation of tissue equivalent doses, each multiplied by the appropriate tissue weighting factor **w**T, to indicate the combination of different doses to several different tissues in a way that correlates well with all stochastic effects combined.

$$E = \sum W_T \times H_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The unit of the quantity is the Sievert (Sv), which is 1 J kg $^{-1}$. A commonly used subunit is the millisievert (mSv) or one-thousandth of a Sv (Protection, 1990).

Table 2.4: **Tissue weighting factors for different organs**.

Organs	**Tissue weighting factors**		
	ICRP30(1979)	**ICRP60(1990)**	**ICRP103(2007)**
Gonads	0.25	0.20	0.08
Clon	-	0.12	0.12
Lung	0.12	0.12	0.12
Red bone marrow	0.12	0.12	0.12
Stomach	-	0.12	0.12
Bladder	-	0.05	0.04
Breast	0.15	0.05	0.12
Liver	-	0.05	0.04
Esophagus	-	0.05	0.04
Thyroid	0.03	0.05	0.04
Bone surface	0.03	0.01	0.01
Skin	-	0.01	0.01

Brain	-	-	0.01
Salivary	-	-	0.01
Remained	0.03	0.05	0.01

(Protection, 2007)

2.20.4 Organ dose

Organ dose $D_T$is defined as mean dose in a specified tissue or organ T of the human body, given by:

$$D_T = \frac{\varepsilon_T}{m_T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where:

- m_T is the mass of the organ or tissue under consideration.
- ε_T is the total energy imparted by radiation to that tissue or organ.

2.21 Quantities and Units Used in Nuclear Medicine Dosimetery

2.21.1 Becquerel

The becquerel with the symbol Bq. The becquerel is defined as the quantity of radioactive substance that gives rise to a decay rate of 1 decay per second. In medical diagnostic work 1 Bq is a rather small amount of radioactivity. Indeed it is easy to remember its definition if you think of it as a buggerall amount of radioactivity. For this reason the kilobecquerel (kBq) and megabecquerel (MBq) are more frequently used.(Maher and Contributors, 2006).

2.21.2 Curie

The curie is defined as the amount of radioactive substance which gives rise to a decay rate of 3.7×10^{10} decays per second. In other words 37 thousand, million decays per second which as you might appreciate is a substantial amount of radioactivity. For medical diagnostic work the millicurie (mCi) and the microcurie (μCi) are therefore more frequently used(Maher and Contributors, 2006).

2.21.3 Physical, Biologic, and Effective Half-Lives

The calculation of dosimetry relies on an understanding of the different types of half-lives used to describe radiopharmaceuticals. The physical half-life (Tp or T1/2) is the time it takes for half of the nuclide atoms to become stable. The biologic half-life (Tb) has nothing to do with radioactivity, but rather reflects the half-time for excretion of the material from the organ or whole body. For instance, the biologic half-life of 99mTc-MDP is the time it takes for one half of this radiopharmaceutical to be filtered and excreted by the kidneys and bladder. The effective half-life (Te) is a measurement that combines the above two values; it is the time required for one half of the initial radioactivity to disappear from an organ or the body both by excretion and physical decay. The effective half-life is always shorter than either the physical or biologic half-life and is calculated using the formulas

$$1/Te = 1/Tb + 1/Tp \ldots\ldots\ldots (12)$$

Or

$$Te = (Tb \times Tp)/(Tb + Tp) \quad (8)$$

Table 12-3 Sample Physical, Biologic, and Effective Half-Lives

Radiopharmaceutical	T_p	T_b	T_e
^{99m}Tc-sulfur colloid	6 h	∞[a]	6 h
^{99m}Tc-MDP	6 h	4 h	2 h
^{67}Ga-citrate	78 h	530 h[b]	68 h
^{123}I	13 h	26 h	8.7 h
^{131}I (30% uptake)	8 days	70 days	7 days

Note:
[a] Sulfur colloid is taken up by reticuloendothelial cells and has a very slow elimination from the liver, so the biologic half-life of the sulfur colloid is estimated as infinite.
[b] A weighted average of fast and slow

2.21.4 Activity

The number of disintegrations per unit time (disintegration rate), -dN/dt,

of a radionuclide at any time is proportional to the total number of radioactive atoms present at that time. Mathematically,

$$-dN/dt = \lambda N \quad \text{..... (13)}$$

Where N is the number of radioactive atoms and l is a decay constant that is defined as the probability of disintegration per unit time for the radioactive atom. The disintegration rate, dN/dt, is termed the radioactivity or simply the activity of a radionuclide and denoted by A. From the above statements, the following equation can be written:

$$A = \lambda N \quad \text{..... (14)}$$

From a knowledge of the decay constant and radioactivity of a radionuclide, one can calculate the total number of atoms or the total mass of the radionuclide present (using Avogadro's number, 1 g . atom (g.atom) 6.02* 1023 atoms).the SI unit of activity the becquerel (Bq) (Saha and Saha, 2004).

2.21.5 Specific Activity

Specific activity is defined as the radioactivity per unit mass of a radionuclide or a labeled compound. Sometimes it is confused with concentration, which is defined as the radioactivity per unit volume of a sample. For example, suppose that 100 mg 131I-labeled albumin contains 150 mCi (5.55 GBq) 131I radioactivity. Its specific activity would be 150/100, that is, 1.5 mCi/mg or 55.5 MBq/mg. The specific activity of a carrier-free radionuclide sample is related to the half-life of the radionuclide: the shorter the half-life, the higher the specific activity. The specific activity of a carrier-free or NCA radionuclide can be calculated by the following formula

$$\text{Specific activity (mCi/mg)} = \frac{3.13 \times 10^9}{A \times t_{1/2}} \quad \text{..... (15)}$$

Where A is the mass number of the radionuclide, t1/2 is the half-life in hours of the radionuclide. The specific activity of a radiopharmaceutical is an important information for a particular nuclear medicine test and is often provided on the label posted on the vial. Low specific activity is of little value in some labeling procedures because the cold atoms compete with radioactive atoms for the binding sites of the reacting molecules and thus

lower the labeling yield. The SI unit of the specific activity the becquerel (Bq).(Saha and Saha, 2004).

2.22 Literature review

Nur Rahmah Hidayati et al, 2016 are reported of Application of 99mTc Radioisotope in Diagnostic Procedures and Internal Radiation Dose Estimation. The internal dose estimation for 99mTc procedures by using Organ Level Internal Dose Assessment/Exponential Modeling (OLINDA/ EXM) software. The result of calculation was compared between Adult Caucasian model and Asian Reference Man. The result shows that 99mTc has been well applied and developed for diagnostic procedures in Nuclear Medicine Department. Moreover, in most diagnostic procedures using 99mTc in Indonesia, adult patients will receive effective dose about 1-15% higher than adult patient in foreign countries which apply the Caucasian model. Hence,to estimate the similar stochastic risk from the same procedure, the maximum value in recommended administered dose should be avoided and need to be evaluated (Hidayati, 2016).

Isaac K. Wilson, et al 2015 are reported of Estimation of kidney and bladder radionuclide activity for patients undergoing bone scan. The Radionuclide activities in the kidney and bladder have been estimated experimentally from practical data 3 h after injection of Tc-99m MDP, using conjugate view methodology. The study involved sixty-five patient images from the database of a nuclear medicine department in Ghana. Time activity curve was stimulated with Mat Lab computer program using biokinetic model published in MIRD Report 13. The model was used to determine theoretical activities in kidney and bladder, which were compared with the experimental data. Estimated radionuclide activities for the kidney and bladder were both minimal in the experimental case comparative to the theoretical. The fraction

of injected activity in kidney and bladder were less than 1% of injected activity, and hence kidney and bladder could be seen to receive very low doses during bone scans (Bambara et al., 2015).

The department of Medical of Physics from School of Nuclear and Allied Sciences, University of Ghana (Ghana) , 2014 are reported of Evaluation of radiation dose to patients from Tc-99m during bone scan in nuclear medicine at Korle-Bu Teaching Hospital Bambara, T. L. Were Internal dosimetry deals with the measurement of the radiation dose absorbed internally by an organ after the administration of isotopes for diagnosis and treatment. In the present study radiation absorbed dose has been calculated for technetium-99m methylene diphosphonate (Tc-99m MDP) which is used frequently for bone scan in Korle-Bu teaching hospital nuclear medicine department. In these cases a small amount of isotopes are accumulated in kidney, urinary bladder etc. Study on sixty-five patients undergoing bone scans has been performed quantitatively using e.softsoftware. The Tc-99m MDP doses were administered to the patients with activity ranging from 377.4 to 932.4 MBq depending on their weights, and were then scanned with an installed e.Cam SPECT system. A 256 × 1024 matrix size was used in acquiring the bone scans. Also the scans of five volunteer patients at three different times (1 hour, 2 hour and 3 hour after injection) were used to determine the residence time in the bladder and kidney. To determine the amount of activity in patient kidney and urinary bladder, conjugate view method was applied on images information. MIRD equation and OLINDA/EXM software were then used to estimate absorbed dose in different organs of patients. The absorbed value obtained from the two methods were compared. The activity in patient's left kidney, right kidney and urinary bladder undergoing bone scan three hours after injection of Tc-99m were 1.52±0.48 MBq, 1.52±0.44 MBq

4.88±3.11MBq respectively. The residence time for the kidney and urinary bladder were 0.128±0.043 hour and 1.099±0.330 hour respectively. The absorbed dose per unit of injected activity (mGy/MBq) for bladder, kidneys, liver, lungs, red marrow, ovaries, pancreas, skin and spleen were calculated for the male and the female patients using the two methods. The absorbed dose values obtained from the two methods were compared. In the study for absorbed dose calculation, MIRD equation is in agreement with the data of OLINDA/EXM software with the deviation vary from 0.09% to 19.51% depending to the organ but it is possible to use by a clinician (Bambara, 2014). Hamid Javadi, et al, (2013) reported of Radiation exposure from diagnostic nuclear medicine examinations in Golestan province, were the Data of nuclear medicine procedures performed in 2 nuclear medicine departments in Golestan province were collected during 4 years. Effective dose, collective effective dose and effective dose per examination were calculated using standard dosimetry tables. Were Based on the data of this study, results of 10437 nuclear medicine procedures performed during 4 years have lead to 3.97 mSv as average effective dose per examination and 10.37 human-Sv as mean collective effective dose. It was also revealed that Tc-99m was the main source of effective dose (98.3%), bone scan was the most common procedure (25.9%) and cardiac scan (MIBI-rest) has the highest collective effective dose (33.5%) during 4 years. The Beside the cardiac scan which was the most common nuclear medicine procedure and the main contributor of effective dose in patients, due to geographical condition of the northeast of Iran, bone scan was the highest performed nuclear medicine examination in the Golestan province (Javadi et al., 2013).

Daryoush – Shahbazi, et al, (2012) reported of estimation of organ absorbed doses in patients from 99mTc-diphosphonate using the data of mirdose

software, in this study, each patient was injected 25 mCi of 99mTc-MDP. Whole-body images from thirty patients were acquired by gamma camera at 10, 60, 90, 180 minutes after 99mTc-MDP injection. To determine the amount of activity in each organ, conjugate view method was applied on images. MIRD equation was then used to estimate absorbed doses in different organs of patients. At the end, absorbed dose values obtained in this study were compared with the data of MIRDose software. The absorbed doses per unit of injected activity (mGy/MBq × 10-4) for liver, kidneys, bladder wall and spleen were 3.86 ± 1.1, 38.73 ± 4.7, 4.16 ± 1.8 and 3.91 ± 1.3, respectively. The results of this study may be useful to estimate the amount of activity that can be administered to the patient and also showed that methods used in the study for absorbed dose calculation is in good agreement with the data of MIRDose software and it is possible to use by a clinician (Shahbazi-Gahrouei et al., 2012).

Chapter three

Materials and Method

3.1 Materials of the study

•99Mo 99mTc Generator

•Radiopharmaceuticals (Tc 99m MDP)

•Dose calibrator

Gamma camera planar SPECT system

3.2 Subjects

The data in this research collected from 100 adult patients who were selected randomly from group of the patients who were diagnosed bone scan in three nuclear medicine hospital (A, B and C).

3.3 Place and duration of study

This study was conducted in Khartoum state in period from April to August 2018.

3.4 Method of the study

3.4.1 Method of data collection

The data collected including the:

Age, weight, height, gender and activity of the patients**.**

3.4.2 Technique used

Under sterile condition 5mL sodium pertechnetate solution with maximum activity 100-500 mci is add to the vial content through the stopper, the vial content should be mixed an after a period of 20 minute. The pH value of the prepared solution is 5-7. Tc 99m MDP radiopharmaceuticals of choice for skeletal scintigraphy. In order to obtain stable chelated

complexes, reducing agents (SnCl2) are needed, which keep technetium in a low valence state so that binding occurs. After the intravenous administration the 99mTc-MDP accumulated in the kidneys then redistribution starts and accumulation in the skeleton increase. Following IV administration, 99mTc-MDP is cleared from the plasma with a half-time of 3–4 min. About 10% of the injected dosage remains in the blood at 1 h post-injection and less than 1% at 24 h. Urinary excretion is 50% and the remaining 50% is retained by the skeleton in 24 h. Through the natural process of radioactive decay, the small amount of radiotracer in body will lose its radioactivity over time. It may also pass out of patients body through the urine or stool during the first few hours or days following the test. The complex portion which is not bound by bones is excreted through the urinary tract. The 99mTc-MDP elimination through the kidneys copies virtually the time course of it is whole body retention, which half-lives are 30 minutes. The total activity of injection shows up within 6 hours in the urine.

3.5 The protocol of bones scintigraphy:

Radiation Dosimetry in Adults (Donohoe et al., 2003).

Radiopharmaceuticals	Administered Activity MBq (mCi)	Organ Receiving the Largest Radiation Dose* mGy/MBq (rad/mCi)	Effective Dose mSv/MBq (rem/mCi)
^{99m}Tc-phosphates and phosphonates	740–1110 (20–30) Intravenously	Bone 0.063 (0.23)	0.0080 (0.030)

3.6 Dosimetric calculations:

3.6.1 RADAR software

A computer program called RADAR software was used to estimate effective dose of patients. In the early 21st century, an electronic resource was established on the Internet to provide rapid, worldwide dissemination of important dose quantities and data. The Radiation Dose Assessment Resource (RADAR) established a Web site (www.doseinfo-radar.com) and provided a number of publications on the data and methods used in the system. The RADAR system has perhaps the simplest representation of the cumulative dose equation:

$$\mathbf{D = N \times DF}$$

Where N is the number of disintegrations that occur in a source organ, and DF is

$$\mathrm{DF} = \frac{k \sum_i y_i E_i \phi_i}{m}$$

The DF is conceptually similar to the "S value" defined in the MIRD system. The number of disintegrations is the integral of a time-activity curve for a source region. RADAR members produced compendia of decay data, dose conversion factors, and catalogued standardized dose models for radiation workers and nuclear medicine patients, among other resources. They also produced the widely used OLINDA/EXM11 personal computer software code, which used the equations shown here and the input data from the RADAR site. This code was basically a revised version of the highly popular MIRDOSE12 software, which implemented the MIRD method for

internal dose calculations (but was not in any way associated with the MIRD Committee itself). The RADAR site and OLINDA/EXM software implement all of the most current and widely accepted models and methods for internal dose calculations (as are described in the next chapter) and are constantly updated to reflect changes that occur in the science of internal dose assessment. RADAR is now an officially sanctioned committee, like MIRD and the ICRP, and its members have published a number of documents, data sets, and tools with a literature basis that is clearly important to the current practice of dosimetry.(Stabin, 2008).

3.6.2 Dosisrad:

Software program for automatic calculation of the dosimetery of radiopharmaceuticals administered to patients according to the patients age, the type of radiopharmaceutical and administered activity. the resulting dosimetery is showing that, the absorbed doses for each organ in mGy and the effective dose in mSv. The calculation of this software are performed according to the values given by the international commission on radiological protection. **(**Perales and Mendoza, 2015**).**

3.7 Method of data analysis

The data in this study was analyzed with social package of statistical science (SPSS)**.**

Chapter Four
Results

4.1 Results:

The following tables will deals with the highlighting of the results related to 100 patients from three hospitals who were undergoing to the bone scan with gamma camera scanner.

***Table (4.1*) summaries the characteristic statistics parameters for the hospital (A) from the gamma camera:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	56.10	56.00	16.155	21	85	70
Weight	68.57	62.00	18.805	40	125	83
High	162.03	160.00	7.472	148	175	170
BMI	25.93	23.50	6.0511	16	42	29.50
Activity	19.33	19.00	1.583	17	22	20
E by Dosisrad	4.13	4.00	.34575	4	5	4.00
E by RADAR	3.70	4.00	.4661	3	4	4.00

***Table (4.2*) summaries the characteristic statistics parameters for the hospital (A) from the gamma camera, for male:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	62.75	69.50	20.454	21	85	74.50
Weight	74.75	70.50	24,636	40	125	90.25
High	167.33	170.00	6.272	157	175	171.00
BMI	26.33	25.50	7.5237	16	42	30.50
Activity	19.00	19.00	1.651	17	22	20
E by Dosisrad	4.08	4.00	.28863	4	5	4.00
E RADAR	3.58	4.00	.5149	3	4	4.00

Table (4.3) **summaries the characteristic statistics parameters for the hospital (A) from the gamma camera, for female:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	51.67	52.50	11.061	36	73	57.75
Weight	64.44	61.00	12.867	50	93	72.00
High	158.50	158.50	6.061	148	175	161.25
BMI	25.67	23.00	5.0643	21	38	29.50
Activity	19.56	19.50	1.542	17	22	20.25
E by Dosisrad	4.17	4.00	.38348	4	5	4.00
E RADAR	3.78	4.00	.4278	3	4	4.00

***Table (4.4*) summaries the characteristic statistics parameters for the hospital (B) from the gamma camera:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	62.43	65.50	10.129	40	76	70.00
Weight	71.57	68.50	15.017	45	110	80.00
High	163.53	165.00	7.838	147	178	169.25
BMI	26.77	26.00	5.2764	17	43	30.25
Activity	21.30	2.50	2.395	18	25	24.00
E by Dosisrad	4.43	4.00	.50401	4	5	5.00
E RADAR	4.07	4.00	.5208	3	5	4.00

Table (4.5) **summaries the characteristic statistics parameters for the hospital (B) from the gamma camera for male:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	67.50	67.50	5.516	55	76	71.25
Weight	69.07	64.00	15.838	45	98	80.50
High	167.07	168.00	6.735	150	178	170.25
BMI	24.36	23.50	4.4826	17	34	28.00
Activity	19.71	19.00	1.858	18	25	20.00
E by Dosisrad	4.14	4.00	.36314	4	5	4.00
E RADAR	3.86	4.00	0.5345	3	5	4.00

Table (4.6) **summaries the characteristic statistics parameters for the hospital (B) from the gamma camera for female:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	58.00	60.00	11.272	40	74	68.00
Weight	73.75	69.50	14.411	55	110	80.00
High	159.75	160.00	6.836	147	173	164.50
BMI	28.88	27.50	5.1235	23	43	31.75
Activity	22.69	22.50	1.922	20	25	24.75
E by Dosisrad	4.69	5.00	.47871	4	5	5.00
E RADAR	4.25	4.00	.4472	4	5	4.75

Table (4.7) **summaries the characteristic statistics parameters for the hospital (C) from the gamma camera:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	61.07	63.00	15.010	31	89	74.00
Weight	73.07	70.50	13.065	45	104	80.00
High	166.13	164.50	11.464	142	187	175.00
BMI	26.47	26.50	4.191	18	35	29.25
Activity	20.10	20.00	1.788	17	25	21.00
E by Dosisrad	4.20	4.00	.407	4	5	4.00
E RADAR	3.83	4.00	.379	3	4	4.00

Table (4.8) **summaries the characteristic statistics parameters for the hospital (C) from the gamma camera for male:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	67.19	72.00	11.862	38	81	74.75
Weight	76.94	73.00	14.012	56	104	89.50
High	174.38	173.50	7.347	164	187	181.25
BMI	25.19	24.00	4.119	18	33	28.00
Activity	2.38	20.00	2.125	17	24	22.00
E by Dosisrad	4.31	4.00	.479	4	5	5.00
E RADAR	3.81	4.00	.403	3	4	4.00

***Table (4.9*) summaries the characteristic statistics parameters for the hospital (C) from the gamma camera for female:**

	Mean	Median	STD	Min	Max	3d Quartile
Age	54.07	52.50	15.539	31	89	62.25
Weight	68.64	68.00	10.710	45	89	78.00
High	156.71	157.50	7.194	142	168	163.00
BMI	27.93	27.50	3.912	22	35	31.25
Activity	19.79	20.00	1.311	17	22	20.00
E by Dosisrad	4.07	4.00	.267	4	5	4.00
E by RADAR	3.86	4.00	.363	3	4	4.00

***Table (4.10)* comparison between Dosisrad & RADAR software's for effective dose calculated by both:**

Hospitals	ED by Dosisrad mSv	ED by RADAR mSv
A	**4.13**	**3.70**
B	**4.43**	**4.07**
C	**4.20**	**3.83**
Mean	**4.25**	**3.86**

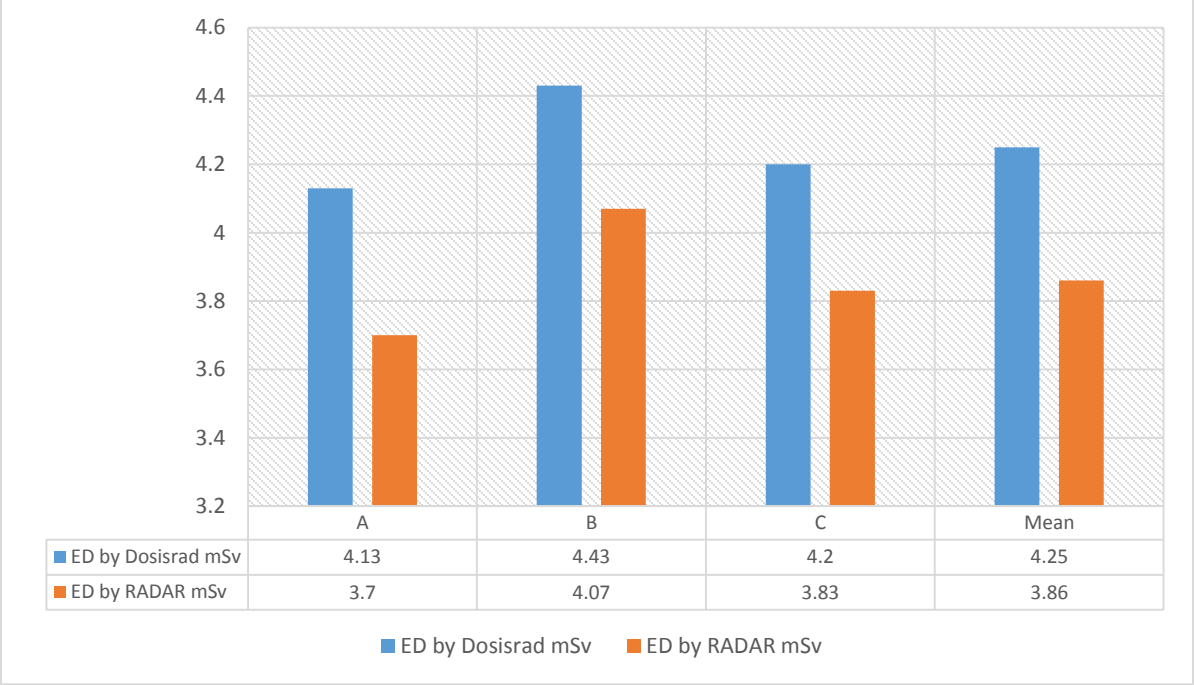


Table (4.11) **showed the organ dose estimated from the gamma cameras scanner by Dosisrad software during this study for hospital (A)**

	Mean	Median	STD	Min	Max	3d Quartile
Adrenal	1.4937	1.4700	.12694	1.30	1.70	1.5500
Bladder	34.1610	33.7400	2.91996	30.00	39.07	35.5200
B. surface	44.8060	44.2800	3.71818	39.00	51.28	46.1550
Brain	1.2537	1.1900	.20191	1.06	1.08	1.2500
S. intestine	1.5640	1.5300	.15053	1.40	1.87	1.6325
Colon	1.9143	1.8900	.14438	1.69	2.19	1.9900
UL. intestine	1.3493	1.3300	.10432	1.19	1.54	1.4000
L. intestine	2.6353	2.5300	.25340	2.37	3.09	2.8025
Kidneys	5.2160	5.1300	.42055	4.59	5.94	5.4000
Ovaries	2.5547	2.5300	.20187	2.26	2.93	2.6150
R. marrow	6.5653	6.4600	.52465	5.78	7.48	6.8000
Tests	1.7050	1.6800	.13434	1.50	1.95	1.7700
Uterus	4.4893	4.4200	.34875	3.96	5.12	4.6600

***Table (4.12*) showed the organ dose estimated from the gamma camera scanner by Dosisrad software during this study for hospital (B)**

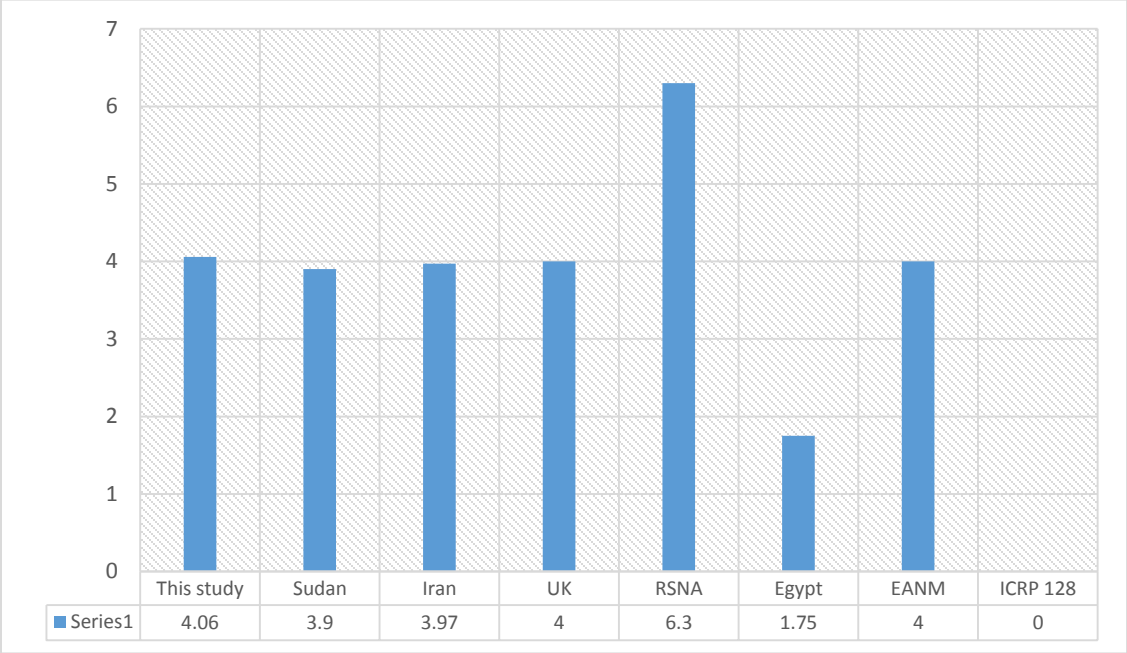
	Mean	Median	STD	Min	Max	3d Quartile
Adrenal	1.6497	1.5900	.18711	1.39	1.94	1.8600
Bladder	37.8260	36.4050	4.25406	31.96	44.40	24.6200
B. surface	49.5017	47.4750	5.66951	41.95	58.27	55.9400
Brain	1.3347	1.2850	.15076	1.13	1.57	1.5000
S. intestine	1.7383	1.6950	.27119	1.40	2.12	2.0400
Colon	2.1200	2.0400	.23947	1.79	2.49	2.3900
UL. intestine	1.7383	1.6950	.27119	1.40	2.12	2.0400
L. intestine	2.1200	2.0400	.23947	1.79	2.49	2.3900
Kidneys	1.4910	1.4350	.16763	1.26	1.75	1.6800
Ovaries	2.9397	2.8750	.39912	2.37	3.51	3.3700
R. marrow	7.2437	6.9700	.81686	6.12	8.51	8.1600
Tests	5.7510	5.5350	.64656	4.86	6.75	6.4800
Uterus	2.8200	2.6950	.32869	2.39	3.33	3.1900

***Table (4.13*) showed the organ dose estimated from the gamma camera scanner by Dosisrad software during this study for hospital (C)**

	Mean	Median	STD	Min	Max	3d Quartile
Adrenal	1.5543	1.5500	.14313	1.30	1.86	1.6300
Bladder	35.6643	35.5200	3.23139	30.00	42.62	37.2900
B. surface	46.3967	46.0000	4.37843	39.00	55.94	48.9500
Brain	1.2587	1.2500	.11063	1.07	1.50	1.3200
S. intestine	1.5370	1.4000	.22058	1.40	2.04	1.7800
Colon	2.0000	1.99000	.17879	1.69	2.39	2.0900
UL. intestine	1.5370	1.4000	.22058	1.40	2.04	1.7800
L. intestine	2.0000	1.9900	.17879	1.69	2.39	2.0900
Kidneys	1.4070	1.4000	.12515	1.19	1.68	1.4700
Ovaries	2.8183	2.8000	.25068	2.39	3.37	2.9500
R. marrow	5.4270	5.4000	.48273	4.59	6.48	5.6700
Tests	1.8043	1.7700	.22106	1.50	2.42	1.8600
Uterus	2.6393	2.6000	.24224	2.26	3.19	2.79000

***Table (4.14)* show the mean of ED in this study and compare with other countries and world commission**

	This study 2018	Sudan 2016	Iran 2013	UK 2008	RSNA 2008	Egypt 2012	EANM 2016	ICRP 128 2015
ED	4.06	3.9	3.97	4.00	6.3	1.75	4.0	4.2-6.3



Chapter Five

Discussion, Conclusion and Recommendation

5.1 Discussion:

Radiation dose calculation for this study have been standardized by implementation and dissemination of tools like Dosisrad and RADAR softwares. The quantities effective dose and organ doses were also calculated and added to list of dose estimation given by the programs. In this study doses were expressed in terms of Activity and Effective dose. This provide an indication of the average absorbed dose in the scanned region and comparing the effective dose calculated by tow softwares (Dosisrad and RADAR) below we will discussion of the result in detail.

Table **(**4.1) , (4.4) and (4.7) from result represented the estimation of (mean, median, STD, min, max and 3 Quartile) and Activity, BMI, ED, calculated by software (Dosisrad and RADAR) were used data collection from Gamma Camera scanner A, B and C are used same protocol and show the three hospitals have the difference mean activity (19.33), (21.30) and (20.10) mCi respectively and show that the effective dose in hospital (B) is highest than hospitals (A) & (C) and the effective dose in hospital (C) is higher than hospital (A) and this different in ED refer to the activity were used and BMI, Age. And this results are correspond by two softwares were calculated. For all hospital A, B, and C in this study the effective dose for male and female are the same values although of same activity and this fact are presented in table (4.2), (4.3) ,(4.5),(4.6),(4.7) and (4.8) for all gamma camera, were the effective dose for male was (3 to 5) mSv and female (3 to 5) mSv by RADAR software, and the value was gated by Dosisrad for

male(4 to 5) mSv and for female (4 to 5) mSv This results are confirm that there are not difference of effective dose between male and female for some examination such as the bone scan for this study.

Table (4.10) from results show the compare of effective dose between the two softwares are used to calculate the effective dose for hospitals, we showed that the effective dose calculated by Dosisrad were higher than the effective dose calculated by RADAR for all hospitals A, B and C and the values were (4.13 and 3.7) mSv, (4.43 and 4.07) mSv and (4.20 and1 3.83) mSv respectively , and show that the mean effective dose in this study for Dosisrad is 4.25 mSv and RADAR is 3.87 mSv, and the mean effective dose for this study was estimated 4.06 mSv.

This difference of ED for both software's (Dosisrad and RADAR) refers to the phantoms are used of two softwares and ICRP recommendations. We have been showed that, The ED is the higher in Dosisrad than RADAR.

The organ doses form gamma camera of this results from all hospitals (A, B and C) was showed in tables (4.11) & (4.12) &(4.13) , such as for this doses: bladder (34.1±2.91, 37.8±4.25and35.6±3.23), bone surface (44.8 ±3.71,49.5 ±5.6 and 46.3 ±4.37),red marrow (6.5 ±0.52,7.2 ±0.81and5.4 ±0.48), kidneys (5.2 ±0.42,1.4 ±0.16 and 1.4 ±0.12), uterus (4.4±0.34,2.8 ±0.39 and 2.6 ±0.25), ovaries (2.5 ±0.20,2.9 ±0.39 and 2.8 ±0.25), colon (2.00±0.17,2.1 ± 0.23 and 1.9±0.14) mSv respectively. Some of this organs have high radiosensetivity such as bone surface and bladder, some of it have low radiosensetivity like colon and ovaries, red marrow and uterus in intermediate of radiosensetivity.as shown that in this result. The radiosenetivity of the organs differ according to the specific nuclear

medicine examination. The above result for organ doses was estimated from bone scan examination. The difference of organ doses in three hospitals refer to amount of the activity was used in each hospital.

Table 4.14 show that the mean the ED comparing with, Iran, United kingdom (UK) and Rradiological Society of North America (RSNA), Egypt, and European Association of Nuclear Medicine (EANM), also International Commission of Radiological protection and the mean of ED was in a good corresponded with, Iran, UK and EANM and it was lower than RSNA and ICRP recommendation, and only higher than Egypt and compare the mean of effective dose for this study with local study in 2016 and were approximately equal to the it.

5.2 Conclusion

The purpose of this study to calculate the amount of effective dose of patients undergoing bone examination by two different softwares, Dosisrad and RADAR, and also the magnitude of radiation doses received by some radiosensitive organs of patients. The results of this study showed that methods used in the study for effective dose and organ doses calculation is in good agreement with data of Dosisrad and RADAR softwares. The effective dose estimate given in mSv and also the organ doses are given in mSv. And we compare the effective dose for this study with different reported values of different countries and world commissions and ED it was corresponding to them. Bone scan most common nuclear medicine procedure and the main contributor of effective dose in patients and highest performed nuclear medicine examination in the Khartoum state hospitals.

5.3 Recommendations:

• The technologists in nuclear medicine department must follows the correct procedures for the activity administration to the patients.

• Assay of the doses before injection to the patients, to ensure the typical dose given to the patients.

• Administration individual patient by dose according to the age, BMI of patients to optimize the ED.

• Must using DRLs if it's founded or establish DRLs according to ICRP recommendation.

• Must their be balance between the dose of patient and image quality

• Accurate dosimetry of patients for estimate the radiation dose and risk from nuclear medicine examinations such as bone scan and to optimize use the radio diagnostic techniques.

• Select the software programs for radiation doses estimate according to the specific examination we needed to do. RADAR software is best form the optimization side for effective dose calculate but it cannot give radiation doses of organs, only one organ, and Dosisrad can estimate radiation doses for individual organ and we can use both of them to radiation doses estimate.

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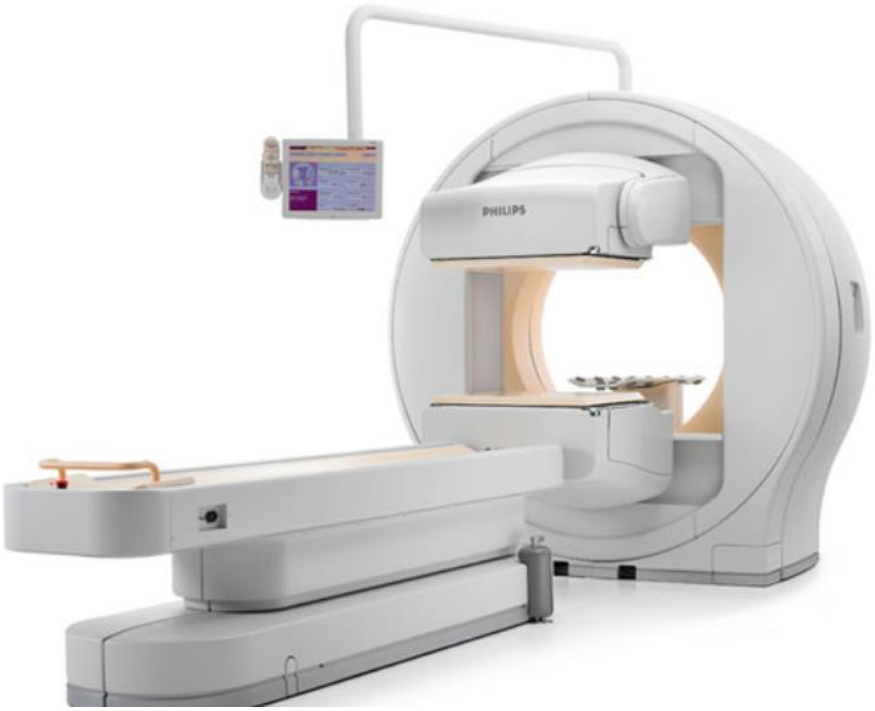
Appendix

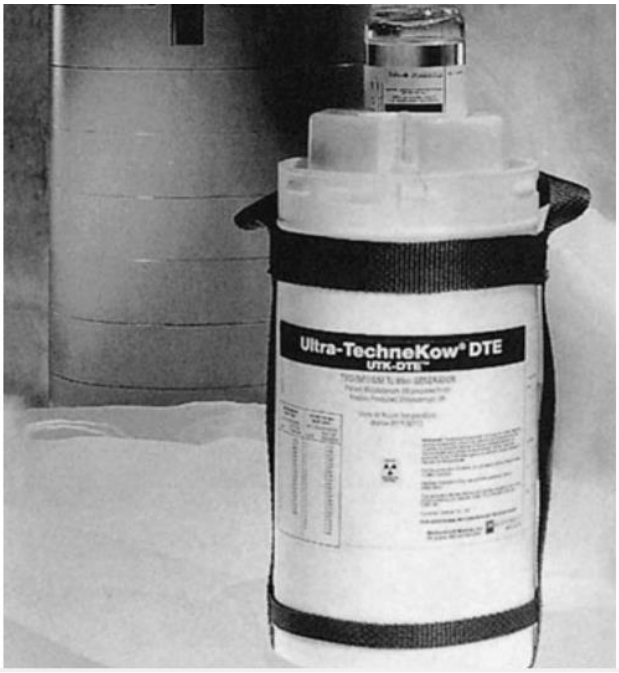
Appendix

Table for Sheet of data collections

Patient No	Gender	Height	Weight	Age	Activity



A SPECT scintillation camera, Philips BrightView X. (Courtesy of Philips Healthcare.)



A 99Mo 99mTc generator (Ultra Technekow DTE). (Courtesy of Mallinckrodt Medical, Inc.)

Figure: showed the MDP (The Radiopharmacy A Technologist's Guide. EANM).

A number of identical photomultiplier tubes from a Gamma Camera