CHAPTER ONE

1.1 Introduction

Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the severity of or treat a variety of diseases, including many types of cancers, heart disease, gastrointestinal endocrine, neurological disorders and other abnormalities within the body.

Because nuclear medicine procedures are able to pinpoint molecular activity within the body, they offer the potential to identify disease in its earliest stages as well as a patient’s immediate response to therapeutic intervention.

Nuclear medicine imaging procedures are noninvasive and, with the exception of intravenous injections, are usually painless medical tests that help physicians diagnose and evaluate medical conditions.

These imaging scans use radioactive materials called radiopharmaceuticals or radiotracers.
Depending on the type of nuclear medicine exam, the radiotracer is either injected into the body, swallowed or inhaled as a gas and eventually accumulates in the organ or area of the body being examined.

Radioactive emissions from the radiotracer are detected by a special camera or imaging device that produces pictures and provides molecular information.

In many centers, nuclear medicine images can be superimposed with computed tomography (CT) or magnetic resonance imaging (MRI) to produce special views, a practice known as image fusion or registration. These views allow the information from two different exams to be correlated and interpreted on one image, leading to more precise information and accurate diagnoses. In addition, manufacturers are now making single photon emission computed tomography/computed tomography (SPECT/CT) and positron emission tomography/computed tomography (PET/CT) units that are able to perform both imaging exams at the same time. An emerging imaging technology, but not readily available at this time is PET/MR.
Nuclear medicine also offers therapeutic procedures, such as radioactive iodine (I-131) therapy that use small amounts of radioactive material to treat cancer and other medical conditions affecting the thyroid gland, as well as treatments for other cancers and medical conditions. Non-Hodgkin's lymphoma patients who do not respond to chemotherapy may undergo radio immune therapy (RIT). Radio immunotherapy (RIT) is a personalized cancer treatment that combines radiation therapy with the targeting ability of Immunotherapy, a treatment that mimics cellular activity in the body's immune system.

:Problem of study  .2

Evaluation the room design for SPECT Gamma Camera is not conducted in Sudan to the best of the researcher's knowledge

:Importance of study  .3
This is the first research in this topic in Sudan and could be used as reference for SPECT room design in the future in Sudan as general.

**Objectives of study 4**

**General objective 4.1**

To evaluate the room design for SPECT Gamma Camera in Alnilain- and RICK for nuclear medicine centers.

**Specific objectives 4.2**

To assess the room design for SPECT gammaCamera in Alnilain- and RICK for nuclear medicine centers.

To measure all the room's dimensions, including walls, ceilings, - floors in the Radiation and Isotopes Center of Khartoum and Alnailin Centers.

To calculate the doses received by workers in nuclear medicine - department and make sure that radiation dose to workers is .within the range of the national and international standards.
To determine the annual doses of workers of the two centers under study.

: **study outlines-5**

:This study consists of the following

Chapter one: deals with introduction, Problem, Importance of study, and objectives

Chapter two: literature review

Chapter three: materials and methods

Chapter four: deals with results and discussion

Chapter five: conclusion and recommendations

References
Appendices
CHAPTER TWO

Literature Review

Theoretical background 2.1

Introduction 2.1.1

The design of a nuclear medicine department should take account of several issues including radiation protection, air quality and infection control.
It is important to consult with the RPA, the radio pharmacist, Medical physicist, the infections control officer and the radiologist or nuclear medicine physician throughout the design phase (NHS, 2001).

Where no radio pharmacist is available, the advice of a pharmacist should be sought.

**Location and access nuclear medicine facility 2.1.2**

A nuclear medicine facility must deal with all the problems of receiving, storing, and handling, injecting Measuring and imaging, and waste disposal for radioactive materials in a hospital setting. In determining location, ease of access for delivery of radioactive material and removal of waste must be considered. These activities may take place out of hours, so design and operational considerations are involved.

Direct egress for patients without going through the busy public areas of the hospital is desirable but not always possible. The requirements for appropriate access for cleaning staff should also be considered at the design stage. (Ireland June 2009)
Ideally all the hospital’s activities involving radioactive material should be centralized into one location to avoid transport of radioactive materials between units. Exceptions to this include some laboratories within the Pathology Service and some research laboratories, some clinical areas such as Endocrinology or Hematology may also use radioactive materials but, as far as possible, the handling of larger amounts of radioactivity should be centralized.

(Ireland June 2009)
Figure (2.1): A possible layout of a nuclear medicine department.
Figure (2.2): A possible layout of equipment in the gamma room.

2.1.3 Nuclear medicine facilities

2.1.3.1 Scanning room

A nuclear medicine imaging unit will have one or more scanning rooms. The scanning room will house the Gamma camera and the operator console.

The size of the room should be sufficient to accommodate the particular type of scanner envisaged and allow for patient trolley access and collimator exchange (typically 35-40m). Scanners with removable tables will need additional space for this facility. (Ireland June 2009)
Patient injection room 2.1.3.2

The patient injection area should be adjacent to the radio pharmacy and should be sized to accommodate one or two bays for ambulatory patients. At least one of the bays should be able to accommodate wheelchair or trolley patients.

Within the room, space should be provided for storage of consumables, shielded sharps and general waste bins, and an instrument trolley; a wash hand basin with elbow or sensor operated taps is also required.

Some level of shielding is likely to be required in this area. The RPA must advise accordingly but 1mm lead is often adequate.

The walls should be clearly marked to indicate the level of shielding provided.

Access to the area should be via a signed and shielded door.

Waiting area 2.1.3.3
Patient waiting areas are required within the nuclear medicine department. Some departments segregate patients pre- and post-administration of radioactive materials. Advice should be sought from the RPA as to whether this is required.

If a significant pediatric workload is envisaged, consideration should be given to a separate waiting area for children. Shielding requirements for the waiting area will depend on location and must be determined by the RPA. Typically, 1-2 mm Lead equivalence is normally adequate. This also applies to any external Windows included in the area. (Ireland June 2009)

**Facilities: WC:2.1.3.4**

WCs for use by nuclear medicine patients only should be provided within the department close to the waiting area. The shielding requirements (if any) for this toilet area must be determined by the RPA. Signs Limiting access to other
Persons should be prominently placed on the doors, as these toilets are likely to be contaminated.

**Reception /office/reporting and consultation 2.1.3.5**

**facilities**

Office, reception, reporting or consultation facilities provided within the nuclear medicine department must comply with the design dose constraint of 0.3 mSv per year. This may be achieved by a combination of size shielding and location.

**The lobby/changing area 2.1.3.6**

A separate gowning/lobby leading to the hot lab/radio pharmacy is required (EANM, 2007). The lobby will be used by staff to change into aseptic clothing and will therefore need appropriate signage and an indication of when it is occupied.
Shelving is required to store the appropriate aseptic clothing and a shielded bin should be available for used and possibly contaminated clothing.

A permanent barrier/demarcation must clearly identify the entrance to the “clean” area. (Ireland June 2009)

**Hot lab and radio pharmacy 2.1.3.7:**

The hot lab accommodates the production functions of the radio pharmacy area and for a single workstation should not be less than 10 m² in area. A hot lab of

Approximately 20 m² should comfortably facilitate two cabinets or isolators.

Area for storage, preparation, and dispensing of radiopharmaceuticals.

It must be secured and provided with adequate shielding. The amount of shielding is determined by a health physicist or radiation safety officer (RSO), depending upon the anticipated usage of specific radioisotopes.
Radionuclide storage area 2.1.3.8

A storage area is required for sealed and unsealed radioactive materials that will be used in the radio pharmacy and should be located adjacent to it.

It may also serve as a central store for much, but not all, of the Radioactive material used in the hospital. Typical dimensions for the storage room might be of the order of 10m² and an appropriately worded warning sign should be prominently displayed on the door and provision for control of access should be made.

The shielding requirements for this area must be determined by the RPA and will depend on the level of the Local shielding of each source or subgroup of sources. (Ireland June 2009)

Nuclear medicine Guide 2.1.4
The nuclear medicine design guide was developed as to assist contracting officer's medical center staff, and Architects, and planners with the design, and construction of nuclear medicine facilities.

It is not intended to be project specific, but rather provide an overview with respect to design and construction of nuclear medicine facilities.

Guide plates for various rooms within nuclear medicine are included to illustrate typical VA furniture, equipment, and personal space needs.

They are not project specific as it is not possible to foresee future requirements.

The project specific space program is the basic of design for an individual project.

It is important to note that the guide plates are intended as a generic graphic representation only.

Equipment manufactures should be consulted for actual dimensions, utilities, shielding, and other requirements as they relate to specified equipment, use of this design guide dose not
supersede the project architects, and engineer's responsibilities to
develop complete and accurate design that meets the user's
needs and complies with appropriate code requirement. (Ireland
June 2009

Definitions 2.1.5

Diagnostic Room 2.1.5.1

Designated room containing diagnostic equipment performing
patient procedures such as Nuclear Medicine, Bone Densitometry,
and PET/CT.

It may also be referred to as Scanning Room, Procedure Room, or
Gantry Room.

"Hot" 2.1.5.2
A colloquial term used to describe the presence of measurable radioactivity. In addition to the nature of the radioactive material itself, the distance from the radioisotope and the time of exposure are important safety considerations.

To keep exposure “as low as reasonably achievable” (ALARA), special waiting / holding areas, toilets and other support spaces may be designed for patients who have received a radioactive substance, depending upon factors including the specific radiopharmaceutical used.

**2.1.5.3 Nuclear Imaging**

Method of producing images using gamma or scintillation cameras that detect radiation from different parts of a patient’s body after administration of a radioactive tracer material. Since physiologic / pathophysiologic processes are being monitored / measured, the patient must remain under the gamma camera for periods of time that vary from 20 to 90 minutes and may return for delayed images later in the same day or several days later. Modalities include Planar and Single Photon Emission Computed Tomography (SPECT) imaging, Positron Emission Tomography (PET), Fusion Imaging and Coincidence Detection imaging. (April 2008)
**Patient Dose Administration 2.1.5.4**

The process of metabolizing delivered radiopharmaceutical agents in order to image the targeted metabolic function.

Patient Dose Administration may require minutes, or even hours, before the imaging process can accurately capture the desired results.

Patient Dose Administration periods will be dependent upon the radiopharmaceutical utilized and the metabolic rate of the tissues/organ targeted.

**Picture Archiving and Communication System 2.1.5.5**

The digital capture, transfer and storage of diagnostic images. A PACS system consists of workstations for interpretation, image/data producing modalities, a web server for distribution, printers for file records, image servers for information transfer and holding, and an archive of off-line information. A computer network is needed to support each of these devices.
Positron Emission Tomography (PET 2.1.5.6)

Positron Emission Tomography, also called PET imaging or a PET scan, is a diagnostic examination that involves the acquisition of physiologic images based on the annihilation radiation of positron-emitting radioisotopes administered to patients. Positrons are tiny particles emitted from a radioactive substance administered to the patient.

The subsequent images of the human body developed with this technique are used to evaluate a variety of diseases. (April 2008)

PET/CT (Combined) Imaging 2.1.5.7

In one examination, a PET/CT scanner combines two state of the art imaging modalities and merges PET and CT images together. By monitoring the body’s metabolism, PET provides information of cell activity whether a growth within the body is cancerous or not. CT simultaneously provides detailed anatomic information about the location, size, and shape of various lesions and tissue. (April 2008)
Radio bioassay 2.1.5.8

This process utilizes specimens such as blood, urine, feces, spinal fluid, biopsies, etc., that are received and/or collected from patients, evaluated, and measured. Radioactive materials are incorporated in vivo or in vitro and determinations of body functions made. Specimen receiving, holding, preparation, examination, interpretation, consultation, record distribution, storage and retrieval occur in areas separate from the clinical imaging function.

Radiopharmaceutical 2.1.5.9

Radiopharmaceutical: Term to describe radioactive agents administered to a patient.

Different agents have an affinity for the varying physiologic processes of the body.

These radioactive substances employed for diagnostic testing/imaging typically have very low doses of radioactivity, enabling patients to be treated on an outpatient basis with minimal restrictions following the exam. (April 2008)
Scintillation or Gamma Camera

Nuclear imaging camera consists of a collection crystal (head) and magnifiers that create images of a target physiologic process from the radiation being emitted from a patient following the administration of a radioactive uptake material.

Single Photon Emission Computed Tomography (SPECT)

Diagnostic imaging modality that usually employs a rotating collection crystal (head) and magnifiers to create three dimensional images of the distribution of single photon emissions from the body.

The images of the varying dimensional relationships are computer generated resulting in improved resolution of target organs / processes. (April 2008)
Room construction standard for nuclear medicine

Floors in offices, conference rooms and waiting areas should be carpet with a 4-inch high resilient base.

Floors in toilet rooms should be ceramic tile with a ceramic tile base.

Floors in imaging units, radio bioassay units and radio pharmacy should have welded seam sheet.

Flooring with an integral base, floors in exam rooms and most other spaces should be vinyl Composition tile with a 4-inch high resilient base.

Treatment rooms and other spaces where higher doses of radiation or longer lived isotopes will be administered should be of welded Seam sheet construction.

Floor assemblies enclosing Nuclear Medicine rooms that require radiation shielding must have the shielding engineered by an appropriately certified Health Physicist.
Refer to H-18-03 VA Construction Standard 64-1, X-Ray Radiation Shielding and Special Control Room Requirements.

Construction documents will require written certification by a registered Health Physicist.

Figure (2.3): A Room Floor in nuclear medicine

Ceiling height should be a minimum of 3 meters, and should be primarily lay-in acoustic ceiling tile.

Certain areas, such as procedure Rooms and treatment rooms should have lay-in acoustic ceiling tile with a washable sprayed Plastic finish.
Coordinate the ceiling height requirements with the equipment manufacturer.

Pathways above ceilings for cable assemblies should be provided for specific equipment type.

Ceiling assemblies enclosing Nuclear Medicine rooms that require radiation shielding must have the shielding engineered by an appropriately certified Health Physicist. (April 2008)

Refer to H-18-03 VA Construction Standard 64-1, X-Ray Radiation Shielding and Special Control Room requirement.

Construction documents will require written certification by a registered Health Physicist.

Wall and corner guards should be used in corridors and all other areas where damage from Cart and stretcher traffic is anticipated.

**Interior Doors and Hardware 2.1.6.1**

Interior doors should be 1 ¾ inch thick solid core flush panel wood doors or hollow metal doors in hollow metal frames.

Door jambs, except in rooms with radiation shielding, should from the floor to facilitate mopping, Doors in wall assemblies that
require shielding must be rated to provide the same shielding Level as that in adjacent partitions.

Hollow metal doors should be used where high impact is a concern and where fire rated doors are required.

Kick / mop plates should generally be applied to both sides of the doors.

Handicapped accessible hardware should be used throughout.

Doors leading to radionuclide receiving and storage area and radio pharmacy are required to be steel security doors that may in some areas need to have proper lead shielding.

Refer to VA Handbook PG-18-14, Room Finishes, Door and Hardware Schedule, for additional information.

**Shielding 2.1.6.2**

Radiation shielding is often necessary to protect adjacent occupancies, Give proper consideration to the weight of shielded partitions, doors, ceilings and floors.
In some instances, Structural building materials may provide adequate levels of radiation shielding in specific directions and may not require additional layers of supplemental shielding. Floor depressions and/or door jamb reinforcement are sometimes necessary.

(April 2008)

**Single-photon Emission Computed Tomography (SPECT)**

SPECT, or less commonly, SPET, is a nuclear medicine tomographic imaging technique using gamma rays. It is very similar to conventional nuclear medicine planar imaging using a gamma camera. However, it is able to provide true 3D information. This information is typically presented as cross-sectional slices through the patient, but can be freely reformatted or manipulated as required.

The technique requires delivery of a gamma emitting radioisotope (a radionuclide) into the patient, normally through injection into the bloodstream.
On occasion, the radioisotope is a simple soluble dissolved ion, such as a radioisotope of gallium (III). Most of the time, though, a marker radioisotope is attached to a specific ligand to create a radiology, whose properties bind it to certain types of tissues. This marriage allows the combination of ligand and radiopharmaceutical to be carried and bound to a place of interest in the body, where the ligand concentration is seen by a gamma camera.

Figure (2.4): A Siemens brand SPECT scanner, consisting of two gamma cameras.

Principle 2.1.7.1

Instead of just "taking a picture" of anatomical structures, a SPECT scan monitors level of biological activity at each place in the 3-D region analyzed. Emissions from the radionuclide indicate
amounts of blood flow in the capillaries of the imaged regions. In the same way that a plain X-ray is a 2-dimensional (2-D) view of a 3-dimensional structure, the image obtained by a gamma camera is a 2-D view of 3-D distribution of a radionuclide.

SPECT imaging is performed by using a gamma camera to acquire multiple 2-D images (Also called projections), from multiple angles. A computer is then used to apply a tomographic reconstruction algorithm to the multiple projections, yielding a 3-D data set.

This data set may then be manipulated to show thin slices along any chosen axis of the body, similar to those obtained from other tomographic techniques, such as magnetic resonance imaging (MRI), X-ray computed tomography (X-ray CT), and positron emission tomography (PET).

SPECT is similar to PET in its use of radioactive tracer material and detection of gamma rays. In contrast with PET, however, the tracers used in SPECT emit gamma radiation that is measured directly, whereas PET tracers emit positrons that annihilate with
electrons up to a few millimeters away, causing two gamma photons to be emitted in opposite directions.

A PET scanner detects these emissions "coincident" in time, which provides more radiation event localization information and, thus, higher spatial resolution images than SPECT (which has about 1 cm resolution). SPECT scans, however, are significantly less expensive than PET scans, in part because they are able to use longer-lived more easily obtained radioisotopes than PET.

Because SPECT acquisition is very similar to planar gamma camera imaging, the same radiopharmaceuticals may be used. If a patient is examined in another type of nuclear medicine scan, but the images are non-diagnostic, it may be possible to proceed straight to SPECT by moving the patient to a SPECT instrument, or even by simply reconfiguring the camera for SPECT image acquisition while the patient remains on the table. (www.heart
The patient lies on a table that slides through the machine, while a pair of gamma cameras rotates around her.

To acquire SPECT images, the gamma camera is rotated around the patient. Projections are acquired at defined points during the rotation, typically every 3–6 degrees. In most cases, a full 360-degree rotation is used to obtain an optimal reconstruction.
The time taken to obtain each projection is also variable, but 15–20 seconds is typical. This gives a total scan time of 15–20 minutes.

Variable, but 15–20 seconds is typical. This gives a total scan time of 15–20 minutes.

Multi-headed gamma cameras can provide accelerated acquisition.

For example, a dual-headed camera can be used with heads spaced 180 degrees apart, allowing two projections to be acquired simultaneously, with each head requiring 180 degrees of rotation.

Triple-head cameras with 120-degree spacing are also used. Cardiac gated acquisitions are possible with SPECT, just as with planar imaging techniques such as Multi Gated Acquisition Scan (MUGA).

Triggered by electrocardiogram (EKG) to obtain differential information about the heart in various parts of its cycle, gated myocardial SPECT can be used to obtain quantitative information about myocardial perfusion, thickness, and contractility of the myocardium during various parts of the cardiac cycle, and also to
allow calculation of left ventricular ejection fraction, stroke volume, and cardiac output

:APPLICATION 2.1.7.2

SPECT can be used to complement any gamma imaging study, where a true 3D representation can be helpful, e.g., tumor imaging, infection (leukocyte) imaging, thyroid imaging or bone scintigraphy. Because SPECT permits accurate localization in 3D space, it can be used to provide information about localized function in internal organs, such as functional cardiac or brain imaging.

:Gamma camera 2.1.8

A gamma camera, also called a scintillation camera or Anger camera, is a device used to image gamma radiation emitting radioisotopes, a technique known as scintigraphy.
The applications of scintigraphy include early drug development and **nuclear medical imaging** to view and analyses images of the human body or the distribution of medically injected, inhaled, or ingested **radionuclides** emitting Gamma rays.

**Construction 2.1.8.1**

A gamma camera consists of one or more flat crystal planes (or detectors) optically coupled to an array of in an assembly known as a "head", mounted on a gantry.

The gantry is connected to a computer system that both controls the operation of the camera as well as acquisition and storage of acquired images.

The construction of a gamma camera is sometimes known as a **compartmental radiation construction**.

The system accumulates events, or counts of **gamma photons** that are absorbed by the crystal in the camera.

Usually a large flat crystal of **sodium iodide** with thallium doping in a light-sealed housing is used.
The highly efficient capture method of this combination for detecting gamma rays was discovered in 1944 by Sir Samuel Curran whilst he was working on the Manhattan Project at the University of California at Berkeley.

Nobel prize-winning physicist Robert Hofstadter also worked on the technique in 1948.

The crystal scintillates in response to incident gamma radiation. When a gamma photon leaves the patient (who has been injected with radioactive), it knocks an electron loose from an iodine atom in the crystal, and a faint flash of light is produced when the dislocated electron again finds a minimal energy state.

The initial phenomenon of the excited electron is similar to the effect and (particularly with gamma rays) the Compton effect.

After the flash of light is produced, it is detected by Photomultiplier tubes (PMTs) behind the crystal detect the fluorescent flashes (events) and a computer sums the counts. The computer reconstructs and displays a two dimensional image of the relative spatial count density on a monitor.
This reconstructed image reflects the distribution and relative concentration of radioactive tracer elements present in the organ and tissues imaged.

(Figure 2.6): An old Anger gamma Camera

Radiation Protection 2.1.9

Because radiation can cause damage in living systems, international and National organizations have been established to set guidelines for the safe Handling of radioactive materials.
The International Committee on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) are two such organizations. They set guidelines for all radiation workers to follow in handling radiations. The NRC adopts these recommendations into regulations for implementing Radiation protection programs in the U.S. At present, the 10CFR20 contains all major radiation protection regulations applicable in the U.S. Since it is beyond the scope of this book to include the entire 10CFR20, only the relevant Highlights of it are presented here.

**ALARA Program 2.1.9.1**

The dose limits are the upper limits for radiation exposure to individuals. The NRC has instituted the ALARA (as low as reasonably achievable) concept to Reduce radiation exposure to individuals. The ALARA concept calls for a reasonable effort to maintain individual and collective doses as low as possible.
Principles of Radiation Protection 2.1.9.2

Of the various types of radiation, the a particle is most damaging due to its great charge and mass, followed by the b particle and the gray. Heavier particles have shorter ranges and therefore deposit more energy per unit path length in the absorber, causing more damage. These are called none penetrating radiations. (Copal B. Saha, PhD)

On the other hand, g and x-rays have no charge and mass and therefore have a much longer range in matter. These electromagnetic radiations are called penetrating radiations.

Knowledge of the type and energy of Radiations is essential in understanding the principles of radiation protection. The cardinal principles of radiation protection from external sources are based on time, distance, shielding, and activity.

Time 2.1.9.3
The total radiation exposure to an individual is directly proportional to the time the person is exposed to the radiation source. The longer the exposure, the higher the radiation dose. Therefore, it is wise to spend no more time than necessary near radiation sources.

**Distance 2.1.9.4**

The intensity of a radiation source, and hence the radiation exposure, varies inversely as the square of the distance. It is recommended that an individual remains as far away as possible from the radiation source. Procedures and Radiation areas should be designed such that only minimum exposure takes place to individuals doing the procedures or staying in or near the radiation areas.

**Shielding 2.1.9.5**

Various high atomic number (Z) materials that absorb radiations can be used to provide radiation protection. (Copal B. Saha, PhD)
Since the ranges of a and b particles are short in matter, the containers themselves act as shields for these radiations. However, gamma radiations are highly penetrating, and therefore highly absorbing material must be used for shielding of g-emitting sources for economic reasons. Lead is most commonly the concept of half value layer (HVL) of an absorbing material for penetrating radiations. It is defined as the thickness of shielding design of shielding for radiation protection. That reduces the exposure from a radiation source by one half.

Thus, an HVL of an absorber placed around a source of radiation with an exposure rate of 100 mR/h will reduce the exposure rate to 50 mR/h. The HVL is dependent on both the energy of the radiation and the atomic number of the absorbing material. The HVL value is greater for high-energy radiations and smaller for high Z materials.

**Activity 2.1.9.6**

It should be obvious that the radiation hazard increases with the intensity of the radioactive source.
The reader the source strength, the more the radiation exposure. Therefore, one should not work unnecessarily with high quantities of radioactivity. (Copal B. Saha, PhD)

**Previous studies 2-2**

After viewing the open literature, especially the internet, and the researchers found few studies in the researcher's study field these included:

Nadia M Sirag1* and Abdelrazek Hussein, (2015) study by DESIGN CONSIDERATIONS TO MINIMIZE STAFF DOSES IN NUCLEAR MEDICINE UNITS and they founded The aim of there was to achieve require to achieve the ALARA principle, to reduce the radiation exposure to workers in the field of the medicine and to minimize as not as possible the staff doses, such that become familiar with the types of sources used in diagnostic and radiation therapy. They also have to be aware of how the basic principles...
of defense in terms of safety of sources and optimization are applied to the design of diagnostic and radiation therapy facilities.

This paper document provides information for a recommended approach for meeting the requirements related to the site description and room design such that the design should maintain the doses As Low as Reasonably Achievable (ALARA).

Haley Coolsaet and Cheri' O'Leary (2015) studied the Effectiveness of using SPECT/CT to reduce operating room times in surgical parathyroid patients. They found that the time was not effective in locating parathyroid adenomas compared to the use of SPECT in regards to a decrease in the amount of time spent in surgery during Parathyroidectomy procedures. However, even though there was no significant difference in the mean surgical times, SPECT/CT is still the preferred acquisition method for Surgeons.

CHAPTER THREE

Materials and methods

:Materials 3.1
Survey Meter Invasion Model 451P Pressurized Certificate No: SAEC/24/014

**Methods of study 3.2**

**Area of the study**: this study was performed at 3.2.1 RICK and Alnilain nuclear medicine centers

**Duration of study**: the study duration was from 3.2.2 December first to 29th of February, 2016

**Data collection**: Data were collected from text books, 3.2.3 references, websites, and personal contact

**Data analysis**: Qualitative and Quantitative description, 3.2.4 statically methods that include arithmetic means, and standard deviation, and the data were processed using computer programs including excel
Figure (3.1): CONTAMAT FHT111M at Alnlain
CHAPTER FOUR

RESULTS

Survey used Invasion Model 451P and CONTAMAT FHT 111 M meter to measure the doses at nuclear medicine department environment (hot lab, gamma camera, waiting room, injection room).

The results were shown in tables [from table (4.1) to table (4.10)], and were summarized in figures [from fig (4.1) to Fig (4.12)].
Table 4.1: Shows dimensions of Rooms measurement for nuclear medicine department in RICK

<table>
<thead>
<tr>
<th>Standard/ m²</th>
<th>Area/m²</th>
<th>Dimensions</th>
<th>Room</th>
</tr>
</thead>
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<tr>
<td>35-40</td>
<td>77.3m²</td>
<td>2.97</td>
<td>4.34</td>
</tr>
<tr>
<td>10-15</td>
<td>17.4m²</td>
<td>2.24</td>
<td>3.93</td>
</tr>
<tr>
<td>Standard/</td>
<td>Area/m²</td>
<td>Dimensions</td>
<td>Room</td>
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<td>------------</td>
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</tr>
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<td>Waiting area</td>
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<td>5</td>
</tr>
<tr>
<td>Hot lab</td>
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<td>Door thickness</td>
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<td>Ceiling high of the imaging room</td>
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<td>-</td>
<td>2.97</td>
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Table 4.2: Shows dimensions of Rooms measurement for nuclear medicine department At Alnilaincenter.
<table>
<thead>
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<th>Width</th>
<th>Length</th>
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<td>Control room</td>
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<td>4.73</td>
<td>3.9</td>
<td></td>
<td>Waiting area</td>
</tr>
<tr>
<td>20</td>
<td>2.1</td>
<td>2.21</td>
<td></td>
<td>Hot lab</td>
</tr>
<tr>
<td>1.75</td>
<td>82.5</td>
<td>2.25</td>
<td></td>
<td>Door</td>
</tr>
<tr>
<td>90</td>
<td>7.2</td>
<td>4.3</td>
<td></td>
<td>Lead Window</td>
</tr>
<tr>
<td>2.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Wall thickness heights</td>
</tr>
<tr>
<td>1.1</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>Door thickness</td>
</tr>
<tr>
<td>3&gt;</td>
<td>2.79</td>
<td>-</td>
<td>-</td>
<td>Ceiling high of the imaging room</td>
</tr>
</tbody>
</table>
Table 4.3: Shows the construction materials of different areas of SPECT Gamma Camera room

<table>
<thead>
<tr>
<th>Material</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Ceiling</td>
</tr>
<tr>
<td>Concrete and ceramic</td>
<td>Wall</td>
</tr>
<tr>
<td>Concrete and chemical</td>
<td>Floor</td>
</tr>
<tr>
<td>.resistant</td>
<td></td>
</tr>
<tr>
<td>Lead and hollow metal</td>
<td>Door</td>
</tr>
<tr>
<td>.doors in hollow frames</td>
<td></td>
</tr>
<tr>
<td>.Lead glass</td>
<td>Window</td>
</tr>
</tbody>
</table>

Table 4.4: Shows the constructions materials different areas of .SPECT Gamma Camera room at Alnilain center

<table>
<thead>
<tr>
<th>Material</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Ceiling</td>
</tr>
<tr>
<td>Concert and ceramic</td>
<td>Wall</td>
</tr>
<tr>
<td>Chemical resistant and ceramic</td>
<td>Floor</td>
</tr>
<tr>
<td>Lead and thickness solid core</td>
<td>Door</td>
</tr>
<tr>
<td>.panel wood door</td>
<td></td>
</tr>
<tr>
<td>.Lead glass</td>
<td>Window</td>
</tr>
</tbody>
</table>
Table 4.5: Shows doses in the presents of injected patients at different areas in Alnilain center

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Floor of I.R</th>
<th>Imaging room</th>
<th>Floor of W.A</th>
<th>Waiting area</th>
<th>Floor of IN.R</th>
<th>Table of IN.R</th>
<th>Injection room</th>
<th>Sink of H.L</th>
<th>Floor of H.L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.32</td>
<td>3.0</td>
<td>7.2</td>
<td>3.0</td>
<td>3.2</td>
<td>0.12</td>
<td>0.691</td>
<td>1.02</td>
<td>13.01</td>
<td>16.0</td>
</tr>
<tr>
<td>0.1</td>
<td>0.01</td>
<td>1.02</td>
<td>0.3</td>
<td>0.92</td>
<td>0.1</td>
<td>0.03</td>
<td>0.09</td>
<td>1.92</td>
<td>3.01</td>
</tr>
<tr>
<td>0.09</td>
<td>0.1</td>
<td>0.691</td>
<td>0.4</td>
<td>0.9</td>
<td>0.09</td>
<td>0.04</td>
<td>1.01</td>
<td>3.0</td>
<td>4.01</td>
</tr>
<tr>
<td>0.2</td>
<td>0.02</td>
<td>3.41</td>
<td>0.693</td>
<td>1.2</td>
<td>0.08</td>
<td>0.09</td>
<td>1.02</td>
<td>7.13</td>
<td>10.2</td>
</tr>
<tr>
<td>0.22</td>
<td>2.0</td>
<td>5.2</td>
<td>2.0</td>
<td>2.2</td>
<td>0.13</td>
<td>0.691</td>
<td>2.1</td>
<td>11.1</td>
<td>14.1</td>
</tr>
<tr>
<td>0.12</td>
<td>0.015</td>
<td>4.34</td>
<td>1.70</td>
<td>2.1</td>
<td>0.630</td>
<td>1.22</td>
<td>2.1</td>
<td>4.74</td>
<td>6.0</td>
</tr>
<tr>
<td>0.11</td>
<td>0.08</td>
<td>3.34</td>
<td>1.4</td>
<td>1.1</td>
<td>0.5</td>
<td>0.09</td>
<td>1.1</td>
<td>3.74</td>
<td>5.0</td>
</tr>
<tr>
<td>0.2</td>
<td>2.07</td>
<td>32</td>
<td>3.50</td>
<td>5.06</td>
<td>0.719</td>
<td>1.15</td>
<td>7.1</td>
<td>6.7</td>
<td>9.00</td>
</tr>
<tr>
<td>0.12</td>
<td>1.06</td>
<td>30</td>
<td>2.50</td>
<td>4.06</td>
<td>0.5</td>
<td>1.0</td>
<td>5.1</td>
<td>4.7</td>
<td>7.00</td>
</tr>
<tr>
<td>0.32</td>
<td>0.25</td>
<td>12</td>
<td>0.965</td>
<td>0.2</td>
<td>60.6</td>
<td>146</td>
<td>62.9</td>
<td>16.5</td>
<td>16</td>
</tr>
<tr>
<td>0.1</td>
<td>0.21</td>
<td>5</td>
<td>0.641</td>
<td>0.1</td>
<td>1.00</td>
<td>1.06</td>
<td>1.09</td>
<td>3.01</td>
<td>4.37</td>
</tr>
<tr>
<td>0.12</td>
<td>0.720</td>
<td>8.42</td>
<td>2.50</td>
<td>0.1</td>
<td>0.09</td>
<td>1.02</td>
<td>1.06</td>
<td>4.70</td>
<td>2.77</td>
</tr>
<tr>
<td>0.1</td>
<td>0.315</td>
<td>6.55</td>
<td>0.55</td>
<td>0.2</td>
<td>5.05</td>
<td>7.55</td>
<td>9.8</td>
<td>1.55</td>
<td>0.941</td>
</tr>
<tr>
<td>0.1</td>
<td>0.12</td>
<td>4.4</td>
<td>0.33</td>
<td>0.1</td>
<td>3.05</td>
<td>5.55</td>
<td>7.8</td>
<td>1.0</td>
<td>0.741</td>
</tr>
<tr>
<td>0.13</td>
<td>0.403</td>
<td>2.25</td>
<td>35.1</td>
<td>15.7</td>
<td>0.389</td>
<td>1.05</td>
<td>2.1</td>
<td>2.69</td>
<td>2.51</td>
</tr>
</tbody>
</table>
Table 4.6: Shows mean ± SD for all variables in nuclear medicine department RICK

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>Corridor</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>Office physics</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Corridor</td>
<td>0.1 ± 0.2</td>
</tr>
<tr>
<td>Waiting area</td>
<td>2.6 ± 1.5</td>
</tr>
<tr>
<td>Imaging room A</td>
<td>1.6 ± 0.9</td>
</tr>
<tr>
<td>Control area</td>
<td>±0.67 0.43</td>
</tr>
<tr>
<td>Imaging room B</td>
<td>0.82 ± 0.92</td>
</tr>
<tr>
<td>Hot lab</td>
<td>2.4 ± 2.9</td>
</tr>
<tr>
<td>Shielding</td>
<td>3.3 ± 5.1</td>
</tr>
<tr>
<td>Inside shielding</td>
<td>6.7 ± 3.9</td>
</tr>
<tr>
<td>Inside door</td>
<td>0.8 ± 1.2</td>
</tr>
<tr>
<td>Waste hot</td>
<td>2.2 ± 2.1</td>
</tr>
</tbody>
</table>
Table 4.7: Shows mean ± SD for all variables in Alnilain of nuclear medicine department

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor of Hot lab</td>
<td>5.7 ± 7.5</td>
</tr>
<tr>
<td>Sink of Hot lab</td>
<td>5.8 ± 6.7</td>
</tr>
<tr>
<td>Injection room</td>
<td>14.6 ± 8.7</td>
</tr>
<tr>
<td>Table of Injection room</td>
<td>32.2 ± 10.4</td>
</tr>
<tr>
<td>Floor of injection room</td>
<td>13.5 ± 5.2</td>
</tr>
<tr>
<td>Waiting area</td>
<td>1.7 ± 2.9</td>
</tr>
<tr>
<td>Floor of waiting area</td>
<td>8.9 ± 4.7</td>
</tr>
<tr>
<td>Imaging room</td>
<td>4.3 ± 8.6</td>
</tr>
<tr>
<td>Floor of imaging room</td>
<td>0.9 ± 1.1</td>
</tr>
<tr>
<td>Corridor</td>
<td>0.2 ± 0.3</td>
</tr>
</tbody>
</table>

Assumed radiation received at two departments
If we assume that the workers spent in these places an average of 6 days \( \text{week} \), 42 weeks \( \text{year} \), the dose received per year could be assumed as follows

Dose per hour x 2 hour per day x 6 days per week x 42 week per year

- **Gamma camera**
  
  .days = 0.9 msv 20
  
  .1day = 0.9/20 = 0.045 msv
  
  .Annual dose = 0.045 x 2 x 6 x 42 = 22.68 msv/y

- **Hot lab**
  
  .days = 2.9 msv 20
  
  .1day = 2.9/20 = 0.145 msv
  
  .Annual dose = 0.145 x 2 x 6 x 42 = 73.08 msv/y

- **Injection room**
  
  .days = 1.4 msv 20
  
  .1day = 1.4/20 = 0.07 msv
  
  .Annual dose = 0.07 x 2 x 6 x 42 = 35.28 msv/y
Table 4.8: shows annual dose received per year at RICK

<table>
<thead>
<tr>
<th>Standard</th>
<th>Average dose /year</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.045x6x42=22.68msv/\text{year}</td>
<td>Gamma camera</td>
</tr>
<tr>
<td></td>
<td>0.145x2x6x42=73.08msv/\text{year}</td>
<td>Hot lab</td>
</tr>
<tr>
<td>50msv/\text{year}</td>
<td>0.07x2x6x42=35.28msv/\text{year}</td>
<td>Injection room</td>
</tr>
</tbody>
</table>

If we assume that the worker spend in these place an average of 3 day/week-21 week/\text{year} the occupancy assumption is:

Dose per hour \times 2 hour per day \times 3 days per weeks \times 21 weeks per year

**: Gamma camera**

\text{.days}=6.0 \text{ msv} \text{ 20}

1 day reading = \frac{0.6}{20}=0.3\text{msv}

\text{Annual dose} = 0.3 \times 2 \times 3 \times 21 = 37.8\text{msv/y}

**: Hot lab**

\text{.days} = 8.7 \text{ msv} \text{ 20}

1 day reading = \frac{8.7}{20}= 0.435 \text{ msv}

\text{Annual dose} = 0.435 \times 2 \times 3 \times 21 = 54.81\text{msv/y}
Injection room

20 days = 7.0 msv

day = 7.0/20 = 0.35msv

Annual dose = 0.35x2x3x21 = 44.1msv/y

---

Table 4.9: shows annual dose at Alnilain center

<table>
<thead>
<tr>
<th>Room</th>
<th>Average dose / year</th>
<th>Standard 50msv/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging room</td>
<td>3x2x3x21 = 37.8 msy</td>
<td></td>
</tr>
<tr>
<td>Hot lab</td>
<td>0.435x2x3x21 = 54.81 msy</td>
<td></td>
</tr>
<tr>
<td>Injection room</td>
<td>0.35x2x3x21 = 44.1 msy</td>
<td></td>
</tr>
</tbody>
</table>
Figure (4.1): Imaging room and injection room doses at RICK

Figure (4.2): Imaging room and waiting room doses at RICK

Figure (4.3): Imaging room and hot lab doses at RICK

Figure (4.4): Hot lab and waiting room doses at RICK

Figure (4.5): Hot lab and imaging room doses at RICK

Figure (4.6): Hot lab and injection room doses at RICK
Figure (4.7): imaging room and injection room doses at Alnilain

Figure (4.8): imaging room and waiting room doses at Alnilain

Figure (4.9): imaging room and hot lab doses at Alnilain

Figure (4.10): hot lab and waiting room doses at Alnilain
Discussion 2.4

This study was conducted at the nuclear medicine departments in Khartoum state and covered two nuclear medicine centers, namely RICK and Alnilain centers. The radiation doses in the two centers were measured at different areas including injected patients waiting area, hot lab, injection room and gamma camera room.

Tables (4.1) and (4.2) showed dimensions of the rooms of all nuclear medicine department. According to these results, the dimensions of the rooms at RICK are bigger than Alnilain center rooms. These because the gamma camera in RICK are bigger (dual head machine), and the number of patients is greater. The dimensions of both centers are adequate for the time being.

Tables (4.3) and (4.4): Showed the construction materials of different areas of SPECT Gamma Camera room. The results
showed that the construction materials of both centers were similar although there were differences of doors material.

Tables (4-5) and (4-6) showed results of survey meter used to measure the doses of the rooms of the two nuclear medicine departments, during the lifetime of the generators. The results showed that the dose at the hot lab during the first day was higher than the other days on which the doses decreased gradually.

As for Alnilain center, the first day dose was the highest dose and the doses decreased gradually at the other days. There were many factors which influence the quantity of the doses namely: the generator activity, the number of injected patients, the presence of other sources in the hot lab and the type of study (dynamic or static).

Tables (4.7) and (4.8) showed the mean ± SD variables, according to which the doses at RICK were lower than the doses received at Alnilain center.

The mean dose of the hot lab were (2.9), injection room (1.4), imaging room (0.9) at RICK. The mean dose of the hot lab at Alnilain center were (7.5), injection room (5.7), imaging room (0.9).
Tables (4.9) and (4.10) showed the assumed annual doses at the injection room, imaging room and hot lab.

The hot lab showed the highest dose followed by the injection room, and the imaging room respectively because the hot lab is the place for patient’s doses preparation (TC\textsuperscript{99m}, I\textsuperscript{131}...etc.) . The injection room’s high dose could be attributed to the number of injected patients, and it is part of the hot lab. As for the imaging room, the dose was low because there was no radiation source and only the patients were the source of radiation.

All the doses were below the national and international standards (50 msv/year for workers), and the results agreed with the previous study done by Nadia M Sirag\textsuperscript{1*} and AbdElrazekZ Hussein.
CHAPTER FIVE
Conclusion, Recommendations and Reference

:Conclusion 5.1

This study was done to evaluate the Room Design of SPECT Gamma Camera in Alnailne and RICK Nuclear Medicine Centers. Many measurements of the imaging room, waiting room, hot lab, and the injection room were done and their results were summarized in tables (4.5) and (4.6) and figure (4.1) to (4.12). The doses received at RICK seemed to be lower than those received at Alnailne center.

It was found that the assumed annual doses received at the injected patients rooms in RICK and Alnailne centers, using survey meter Invasion Model 451P Pressurized and CONTAMAT FHT 111 M, were lower below than the national and international standards, although it was too difficult to know the real annual doses received by workers at the two centers under the study without the use of personal dose meters such as the TLD. This means that the worker of two centers need to wear these devices all the time in order to have the real doses received by them.
It is recommended that an individual remains as far away as possible from the radiation source.

The lead is the best material for gamma ray and x-rays shielding.

Concrete material should always be used when building nuclear medicine departments to prevent the leakage of radiation outside the building.

Encouraging the cooperation between the relevant regulatory bodies in Sudan and the IAEA to provide technical support in terms of training courses and the provision of personal dosimeters for nuclear medicine centers.
More than one nurse in the nuclear medicine department should be available so that they can share the radiation doses received by hand and whole body.

Routine survey to the nuclear medicine department, especially the hot lab, should be done.

To decrease the workers radiation exposure and contamination, decontamination kits should always be kept and fully stocked.

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**(Appendix)**

| Tank | Tank | Mild storage | Storange door | Dose calibrator | Waste bin | Inside door | Inside shielding | Shielding | Hot lab | Imaging room B | Imaging room A | Waiting area | Corridor | Physics Office | Corridor | Reception |
|------|------|--------------|---------------|-----------------|-----------|-------------|-----------------|-----------|---------|----------------|----------------|--------------|----------|----------------|----------|
| 2.9  | 2.6  | 1.9          | 2.2           | 1.1             | 0.01      | 0.02        | 0.55            | 0.31      | 0.01    | 0.07           | 0.72           | 0.85         | 0.08     | 0.06           | 0.09     | 0.03 |
| 2.9  | 2.7  | 1.6          | 2.3           | 2.00            | 0.1       | 0.92        | 4.9             | 0.37      | 0.42    | 0.08           | 0.71           | 1.01         | 0.07     | 0.08           | 0.07     | 0.09 |
| 3.0  | 2.1  | 1.2          | 1.3           | 2.1             | 0.26      | 0.72        | 0.29            | 0.2       | 0.26    | 0.02           | 0.42           | 0.48         | 0.09     | 0.04           | 0.01     | 0.03 |
| 2.9  | 2.2  | 1.9          | 1.8           | 0.3             | 1.9       | 1.9         | 3.5             | 10.2      | 0.7     | 0.01           | 0.03           | 0.09         | 0.08     | 0.05           | 0.09     | 0.09 |
| 3.2  | 2.3  | 1.5          | 1.8           | 0.01            | 0.09      | 0.7         | 1.7             | 4.5       | 0.07    | 0.12           | 1.77           | 0.09         | 0.07     | 0.04           | 0.07     | 0.02 |
| 3.6  | 3.4  | 1.6          | 0.5           | 4.1             | 1.9       | 1.9         | 28              | 11.9      | 1.9     | 0.05           | 0.6            | 1.84         | 3.7      | 0.06           | 0.08     | 0.03 |
| 3.9  | 3.4  | 1.5          | 2.4           | 2.1             | 2.1       | 0.7         | 11.3            | 9.1       | 9.00    | 0.5            | 2.4            | 7.0          | 10.4     | 0.3            | 0.09     | 0.8  |
| 3.3  | 3.4  | 1.6          | 2.3           | 2.6             | 0.7       | 0.6         | 10.3            | 9.00      | 9.1     | 0.5            | 2.0            | 1.2          | 6.5      | 0.4            | 0.07     | 0.4  |
| 6.1  | 3.1  | 5.4          | 0.4            | 3.1             | 1.1       | 0.8         | 1.9             | 8.6       | 3.5     | 1.39           | 0.07           | 2.1          | 1.8      | 0.1            | 0.09     | 0.03 |
| 5.1  | 3.0  | 1.7          | 0.3            | 0.6             | 0.8       | 1.3         | 0.4             | 4.1       | 2.1     | 1.4            | 0.03           | 0.01         | 0.3      | 0.13           | 0.06     | 0.10 |
| 4.1  | 3.2  | 1.9          | 0.2            | 0.9             | 0.7       | 2.5         | 0.38            | 7.1       | 4.1     | 1.2            | 0.05           | 0.01         | 0.6      | 0.2            | 0.06     | 0.05 |
| 5.0  | 3.3  | 2.0          | 0.4            | 0.9             | 0.65      | 1.4         | 0.24            | 4         | 3.2     | 2.7            | 0.3            | 0.07         | 0.6      | 0.2            | 0.04     | 0.03 |
| 6.0  | 3.2  | 1.4          | 0.3            | 0.7             | 5.7       | 1.1         | 4.5             | 4.8       | 3.7     | 1.19           | 0.3            | 0.04         | 0.64     | 0.39           | 0.06     | 0.07 |
| 3.1  | 3.4  | 0.3          | 0.1            | 0.5             | 4.5       | 2.1         | 0.23            | 3.5       | 2.4     | 2.0            | 0.07           | 0.05         | 1.1      | 0.26           | 0.02     | 0.05 |
| 6.0  | 3.0  | 0.3          | 4.1             | 3.1             | 1.1       | 0.5         | 1.7             | 6.5       | 2.2     | 1.3            | 0.06           | 1.1          | 1.8      | 0.1            | 0.07     | 0.02 |
| 3.8  | 3.5  | 0.4          | 1.5             | 0.7             | 1.2       | 0.3         | 0.3             | 4.1       | 2.1     | 1.3            | 0.02           | 0.01         | 0.2      | 0.1            | 0.05     | 0.12 |
| 3.6  | 3.3  | 0.3          | 0.6             | 5.4             | 2.1       | 0.21        | 3.1             | 2.5       | 2.2     | 0.05           | 0.03           | 1.0          | 0.1      | 0.01           | 0.04     | 0.05 |
| 3.2  | 3.4  | 0.2          | 1.3             | 0.6             | 5.7       | 1.1         | 4.2             | 4.3       | 3.0     | 1.19           | 0.2            | 0.03         | 0.53     | 0.21           | 0.07     | 0.05 |

*(shows doses in the presence of injected patients at different areas in RICK (μSv/h)*

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### Data collection at Alnilain

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Floor of I.R</th>
<th>Imagining Floor</th>
<th>Waiting Area</th>
<th>Floor of W.A</th>
<th>Table</th>
<th>Injection Room</th>
<th>Sink</th>
<th>Floor of H.L</th>
</tr>
</thead>
</table>
Figure (5.1): The imaging room at RICK

Figure (5.2): Control room at RICK
.Figure (5.3): The imaging room at Alnilain

 .Figure (5.4): The Control room at Alnilain
Figure (5.5): The door of Alnilain Center

Figure (5.6): The door of RICK Center
Figure (5.5): The layout of nuclear medicine department at RICK
Figure (5.6): The layout of nuclear medicine department