Original Research Paper

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Nuclear Medicine

"MODERN PHYSICS AND MEDICAL DIAGNOTICS"

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ABSTRACT This article focuses on the latest advances in medical science that followed recent developments in physics. The domain of physics covers vast area of scientific knowledge. Basic research on assemble of atomic or nuclear radiation and gyromagnetic moments led to powerful technique for studying molecular structure as well as solid lattices. Physics have important role in medical science, nuclear medicine is one of them , as we can easily understand by name nuclear medicine is the method of cure, diagnoses or detect a diseases in which we use very small amount of radioactive materials or radiopharmaceuticals nuclear. The origin of nuclear medicine in India lies in the roots of development of number reactors. The extraordinary efforts of dr.bhabha and hard work of our scientist as well as the support provided by Indian government and many other major contributors such as BARC and BRIT , today India is one of the leading countries in the field of nuclear medicine.

KEYWORDS : Technetium-99m, Radioactive Tracers, Nuclear Medicine, Medical Physics.

"When you change the way, you look at things, the things you look at, change." - Max Plank

INTRODUCTION: -

We are living in the century of science and technology which is changing rapidly. Being one of the oldest and most fundamental scientific disciplines, physics can be considered as the backbone of science, before going into details and facts we must have an understanding, that what is physics and what is its main goal is, so we can define the physics as follows:

"Physics is a branch of science that studies matter, its fundamental constituents, its motion and behavior thorough the space and time."

The main goal of physics is to understand and explain how this universe behaves.

In this modern era physics is as vital and important for the field of science as water for the human body. If we look around us, we can easily find out that how very simple and concise laws of physics operating this huge machinery from which our whole universe is consist of, ranging from subatomic level to the vast galaxies with the length of thousands of light years. Physics is the language of this universe; the range of its applications is countless; with the help of physics, we can explain the motion of a pendulum and the time delay near a massive object such as black hole.

Here we are going to talk about how physics plays a major role in the field of medical. The branch of physics which is related to prevention, diagnosis and treatment of human diseases is known as Medical Physics'. We can define the Medical Physics as follows:

"Medical Physics is a branch of physics that uses principle, theories and applications of physics to detect and cure diseases"

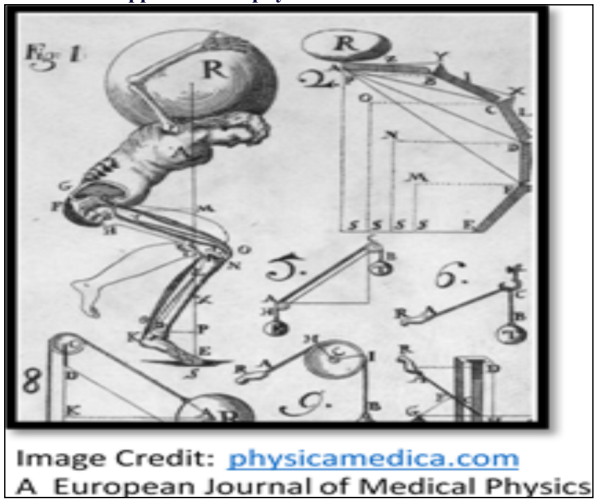

Figure no.1

A Brief History of Medical Physics:-

The traces of links between physics and medicine can be found in some of the oldest intelligent civilizations. An old document from ancient Egypt contains information about the medical use of physics. Greek physician Hippocrates mentioned in one of its writings that how skin temperature distribution could be measured by using wet clay. 'Herophilus' also regarded as the 'Great Greek Physician' had measured the pulse rate using a water clock.

Later an Arabic scholar had shown that human eyes is simply the receiver of light and doesn't emit any beam of energy or particle as some Greek philosophers and scientist had imagined. Some great work related to medical physics came from an Italian physicist Giovanni Borelli, who was the first ever person to place mechanistic ideas to describe the motion of human body. In the above image we can clearly see that how Borelli described the motion of human spine as well as other body parts in terms of physical quantities.

The origin of medical use of modern physics dated old as the discovery of X rays, in the year 1895 the great German physicist and engineer Dr. W.C. Roentgen discovered a new type of radiation while experimenting with cathode rays. Later he realized that it could pass through the opaque objects as well as the human tissue too. Because of this property of X-ray, it could be used in rendering the bones and tissues beneath it. After a year of discovery, the doctors in Europe and U.S. were using Xrays to locate bone fracture, bullets, and stones in human kidney.

The next big turn come in the field of medical physics with the phenomenal work of Rosalyn Yalow who developed a technique known as the 'Radioimmunoassay' through this extremely sensitive and precise technique physician could measure the tiny amount of biological substances with the help of the radioactive materials.

Some other big steps in the direction of medical physics are the invention of 'Computer-assisted tomography' (CT scan) by Allan M Cormack and Godfrey Newbold Hounsfield in 1979, and the invention of **'Magnetic Resonance Imaging'** technique by Paul Lauterbur and Peter Mansfield, this invention later awarded by the Nobel Prize in medicine.

Different Types of Medical Diagnostic Tools: -

There are number of medical diagnostic tools based on the principles of physics such as X-ray, CT scan, MRI, and Nuclear Medicine etc.

Here we going to talk about a special branch of medical physics known as **'Nuclear Medicine'**.

As we can easily understand by name 'Nuclear Medicine' is the method of cure, diagnose or detect a disease in which we use very small amounts of radioactive materials, or radiopharmaceuticals. These radioactive materials also known as radiotracers, typically in the procedure of nuclear medicine swallowed or injected in the blood stream then the radioactive substance travels through the area which is being examined and releases the energy in form of gamma rays which can be easily detected by a special camera known as gamma camera.

After capturing all the images with the help of the camera, we use special computers and software to create 3D images of the interior of the subject.

The process mentioned above is known as 'Nuclear Imaging'. Nuclear imaging provides us some unique information which cannot be obtained by using traditional methods of imaging, also we can detect or cure a serious disease at its earlier stages with the help of nuclear medicines.

Evolution of Nuclear Medicine:-

Nuclear medicine has a long history in which many prestigious scientists, physicists, chemists, and engineers have contributed.

It is difficult to determine a precise origin of this amazing field, but many scientists and researchers believe that the birth of this filed occurred somewhere between 1934, the year in which 'Frederic Joliot-Curie' and 'Irene Joliot Curie' discovered the phenomenon known as artificial radioactivity.

However according to some historians and scientists this remarkable medical idea originated somewhere in mid 1920's by famous Hungarian radiochemist and noble laureate 'George Charles de Hevesy'.

He had done some amazing experiments on rats; with the help of radionuclides, he displayed the metabolic pathways of rats, and we can say that he was the first who established the tracer principle in the field of nuclear medicine.

In 1937 the discovery of Technetium took place by C. Perrier and E. Serge. Technetium is an artificial element which has atomic number 43. Later scientists created a metastable nuclear isomer of Technetium-99 known as Technetium-99m. This discovery can be stated as a milestone in the field of nuclear medicine because Technitium-99m is the first tracer which can be easily traced by the gamma camera. Even today, Technetium-99m is the most used element in this field.

In May,1946 Dr. Saul Hertz and Dr. Arthur Roberts published a paper title as "Radioactive iodine in the study of thyroid physiology; the use of radioactive iodine therapy in hyperthyroidism" in 'Journal of the American Medical Association' in this paper they described how radioactive iodine could be used to treat Grave's Disease.

By the early 1950s American physicist 'Benedict Cassen' invented an imaging device which could be used to capture the energy emission due to the radiopharmaceuticals, but the breathtaking discovery came from a American biophysicist and electrical engineer named as 'Hal O. Anger', he built a camera which could capture the gamma radiation. Today this camera is known as 'Anger Camera' over his name.

By the year 1960 scientist developed a technique in which they used xenon-133 with the help of this phenomenal idea they were successful in drawing the blood flow map of human brain, and by the end of the 1970 most of human organs and their working cycle could be visualized using nuclear imaging techniques.

Nuclear Medicine in India: -

The origin of nuclear medicine in India lies in the roots of development of nuclear reactors. In 1954 Dr. Homi J. Bhabha also regarded as 'Father of Indian Nuclear Program' established AEET (Atomic Energy Establishment, Trombay). The first two nuclear reactors of India, APSARA and CIRUS become operational respectively in year 1956 and 1960. This led us to the production as well as the availability of many radioactive elements with several medical use. In the 1958 the first field unit of radiation cell was established at Safdarjung Hospital, New Delhi. Because of extraordinary efforts of Dr. Bhabha and hard work of our scientist as well as the support provided by Indian government and many other major contributors such as BARC and BRIT, today India is one of the leading countries in the field of nuclear medicine.

Treatment Procedure:-

We can divide the nuclear medicine in the three parts which are as follow:

I. Tracer (Also known as Radiopharmaceuticals)
II. Receiver or Detector (A gamma Camera)
III. Data Analyzer (A set of unique computers and software to analyze data received by detector)

Tracer: -

Tiny amount of radioactive substance which is used during the procedure of nuclear medicine to guild the exam is known as radioactive tracer or radiopharmaceuticals. Human tissues absorb this radioactive substance then the radioactive material start giving off energy in form of gamma radiation which later studied by a gamma camera.

Radiotracer is work like the messenger of internal human body by studying the behavior of these tracers, the healthcare provider can diagnose and cure many serious diseases such as cancer, tumor, infections, hematomas, and organ enlargement etc.

The distribution of radio tracer can be different in the human body, the areas with greater amount of absorption is called 'hot spot' and the areas which do not amount the radionuclide or absorb less amount of it is referred as 'cold spots.

Many elements can be used as the radioactive tracers, isotopes of gallium, iodine, xenon, thallium, and technetium are the most used elements.

Technetium-99m, which is denoted as ^{99m}Tc, is a metastable nuclear isomer of element Technetium.

Technetium-99m is the most used medical radiotracer in the world, here we are going to talk about its working, production, and some precautions which one should have to obey while using this radiotracer.

So, firstly we are going to talk about the working, $^{99m}Tc_{43}$ is swallowed, injected, or inhaled by the patient. Now being a metastable (i.e., excited state of an atom) the $^{99m}Tc_{43}$ has a half-life of only 6 hours, it will quickly decay in $^{99}Tc_{43}$ and gamma radiation. This process can be easily understood by the following reaction.

$$9943mTc \rightarrow 4399Tc + 00Y$$

After this decay we get the $_{43}{}^{99}Tc$ which has a half life of ~25000 year which means it is very stable.

Because $^{99}_{43}{}^{m}Tc$ has a half-life of about 6 hours it is need to produce on site (hospital) or very near the site.

It is produced by the decay of molybdenum. In molybdenum – technetium generator system, molybdenum is parent radionuclide. The general principle for such kind of generator system is that a daughter nuclide with short half-life can be easily isolated.

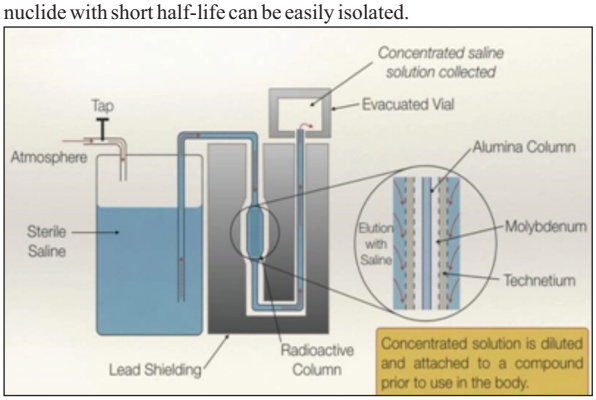

Figure No. 2, Production of $^{99}_{43}{}^{m}Tc$ at hospitals Image credit

From a parent nuclide which has a long half-life. The major requirement to obtain technetium form molybdenum is that the, molybdenum must be in pure form.

There are two reliable and low in cost methode to get good quality molybdenum, one of them is by separation of the material of the fission products of uranium the other one is from neutron activation of cold molybdenum.

After getting pure molybdenum we produce technetiun with the help of above machinary mentioned in the figure – 2.

The whole apparatus has a protection layer of lead so that the workers or hospital staff don't get any fatal dose of radiation.

By the reaction mentioned below we get technetiun from molybdenum.

$4299Mo \rightarrow 9943mTc + -01\beta$

So in the above reaction we can cleary see that the molybdenum decays in technetium-99m and beta particle.

If we look at figure no.3, we can figure out that how the cycle of this generator system works.

This diagram is known as 'Decay energy Level Diagram'. This diagram can be constructed by using energy scale and tabular data. Here in graph we see that peak activity of of technetium occurs at ~ 22-23 hours.

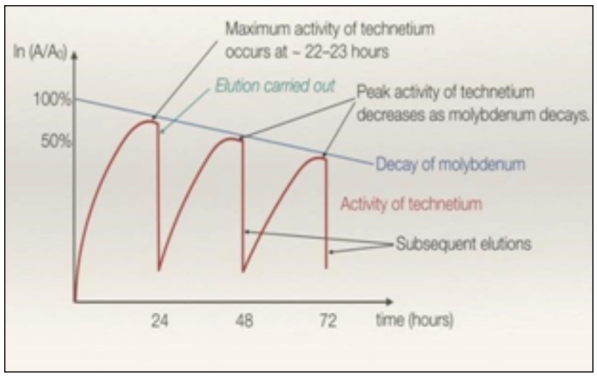

Figure no.3: Decay Energy Level Diagram

Receiver or Detector (Gamma Camera):-
A gamma camera is device which is used by the radiologist to detect the gamma radiation emitted from a radiopharmaceuticals. The gamma camera also known as scintillation camera utilizes the principle of scintillon.

We can divide the 'Gamma Camera' in three parts, collimator, scintillator, and photomultiplier.

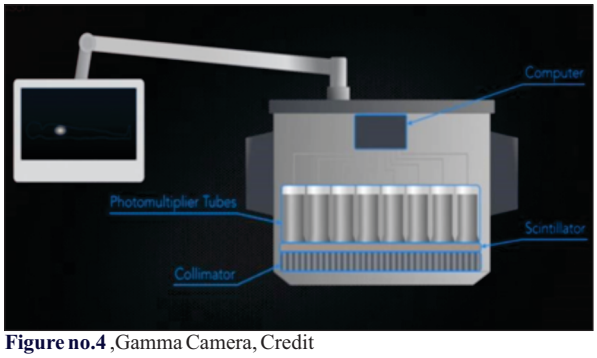

Figure no.4 ,Gamma Camera, Credit

The collimator is the first part of gamma camera. These are basically hollow lead tubes which confirms that only parallel rays reach to the scintillator because if the unparallel rays reached then it is difficult to find the origin of gamma rays which could led to wrong image formation.

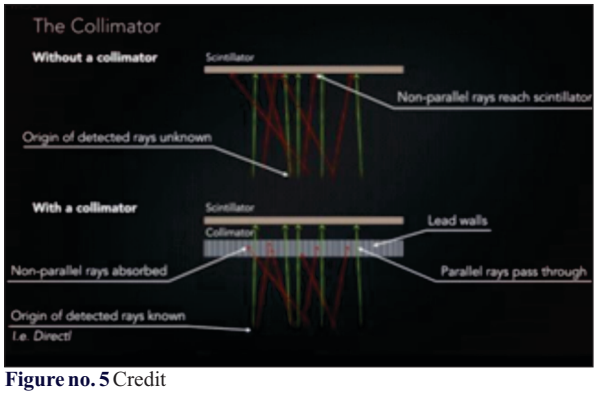

Figure no. 5 Credit

After passing through the collimator the gamma radiation reaches to the scintillator which converts it into visible light. Due to the abortion of energy, there occur creation of primary electron hole pair which generates secondary pair due to the **'cascade effect'.** After this comes the stage of thermalization, after this stage the free electron hole pair migrate through the material, and they transfer their energy to luminescent centers present in the scintillator material. This energy transfer is very quick and takes merely 10^{-12} to 10^{-8} second to be completed. After this energy transfer comes the stage of scintillation. In which, visible light photon emitted by the scintillator.

Here we must remember that the energy of an emitted photon is an important parameter through which we can differentiate between different kinds of radio isotopes.

After this the emitted photon reached inside a photomultiplier tube here, they descended upon a photocathode. Photocathode works on the principle of 'Photoelectric effect'. The photocathode converts these photons of visible light in electric pulses.

Now these electric pulses received by the computer and by the help of these signal computer generates pictures.

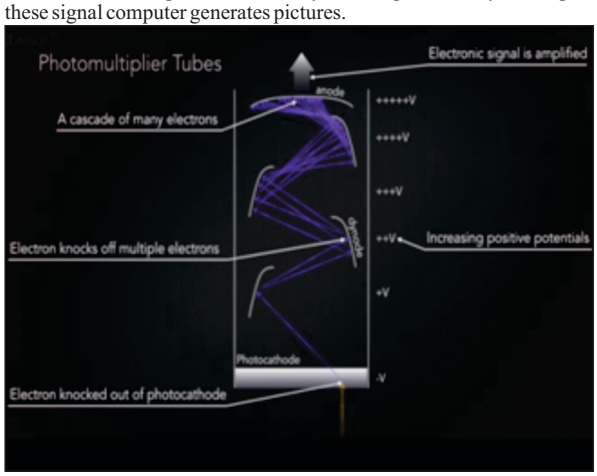

Figure no. 6 Photomultiplier, Credit

Data Analyzer: -
After collecting data from a reciever (A rectilinear scanner of gamma camera) we stacked the images or scan slices either by using analytic algorithms or by iterative algorithms. Generally the radiologist and physician prefer the iterative methode because it has a unique property that correction can be made in all physical quantities and transport of gamma rays can be mathematically modeled.

There are some important parameters for image processing as mentioned below:
- Filtering
- Motion Correction
- Attenuation Correction
- Normal Database
- Volume Fraction Calculation
- Quantification.

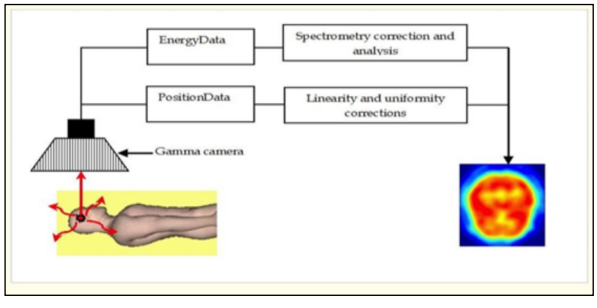

Figure No.7: working of a computer (Data Analyzer)
Credit: Intechopen

This diagram defines that how the image processing works.

Clinicals Applications of Nuclear Medicine: - In Nuclear Medicine we use scans to diagnose any disease.

Some the most common scans are as following:

- **Brain Scan: -** Brain scan is used to monitor the blood circulation of brain, investigate tumors inside brain, detect swelling and any other abnormality.
- **Gallium Scan: -** To diagnose tumors, active infections and inflammatory diseases.
- **Heart Scan:-** In identify abnormal blood flow to the heart, determine the damage of heart tissues after a serious heart attack or to measure the heart funtion.
- **Renal Scans: -** To detect the abnormalities in the renal blood flow.
- **Thyroid and Bone Scans: -** Both these scans are use to diagnose the disease related to thyroid and bones repectively.

Some major protocols during a Nuclear Imaging Process: -

- The patient can not wear any type of jewellery becaue it can interfere with the procedure also have to wear a special type of gown which provided on site.
- The patient will be connected to a ECG machine to monitor his blood pressure as well as his/her other vitals.
- Patients are advised to remain as still as they can to avoid any time of motion blur in images.
- Patients may be asked to change positions to get clear and more precise images of affected area or tissue.

Government's Guildlines to Operate Nuclear Medicine Facilities in India: - There are some common safety measures which have to be followed by every nuclear medicine facility to ensure safety:

- Minimum furniture should be used.
- Top surfaces of worls tables have a smooth laminated finish.
- Remote handing devices should be provided to working staff.
- Ventitalated fume hoods for handing large dose of radiation.
- All the drainage ducts, sinks and toilets should be connected to sanitary facility.

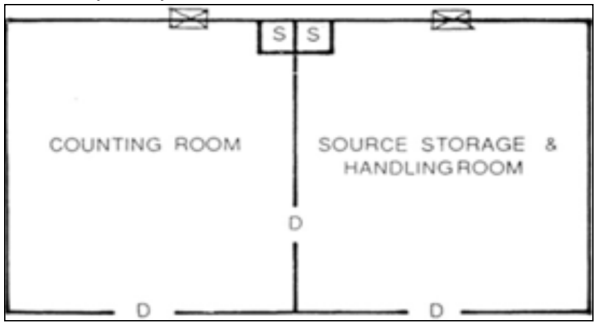

Figure 8:- Credit

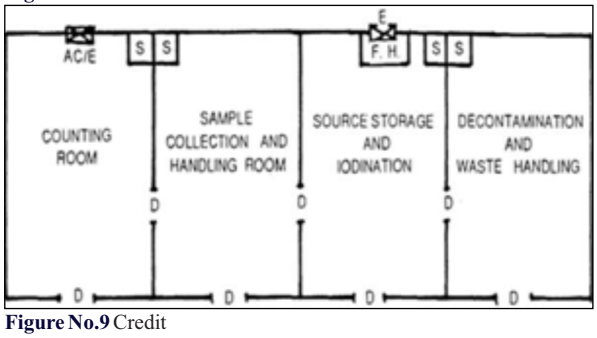

Figure No.9 Credit

Category 3: Laboratories performing in- vivo non imaging procedures and in- vitro assays.

This lab have a total area of ~100m^2

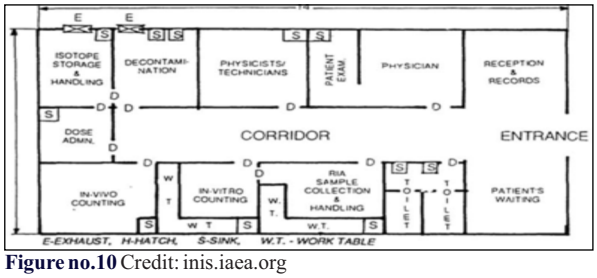

Figure no.10 Credit: inis.iaea.org

Category 4: -

Same as category 3, but this lab also performe some additional experimensts such as, in- vivo static and dynamic imaging procedure.

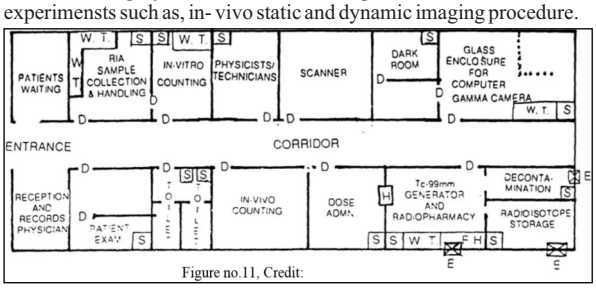

Figure no.11, Credit:

This figure the layout of Category 4 lab. **This lab has Total area: ~200m^2**

CONCLUSION:-

in the end , we can say that physics has been contributing to medical science ever since the birth of science. Some of physics agents such as sound , heat, pressure and light have been used to diagnose and that diseases. Many of the techniques used for examining the eyes and treating ocular disease take advantage of the properties of light. It led to invention and development of modern medical diagnostic and therapeutic tools which have revolutionized the medical practice. Advancement in medical researches as seen today will be well-high impossible without the use of the finding of physics. The funding made of physics is in fact another way of funding made on human health.

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