



**University of Al-Mustaqbal**  
**College of Science**  
**Department of Medical**  
**Physics**



**Medical physics 4**

**Fourth stage/ Second course**

**Radiopharmaceuticals/ /Part 2**

**Lecture Three**

**Name of lecturer**

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## **<sup>99m</sup>Techneium (Tc-99m) – Characteristics**

- is the most widely used radiopharmaceutical in nuclear medicine due to its ideal physical, radiological, and chemical properties.
- It decays predominantly by isomeric transition (IT) to technetium-99, emitting a single gamma photon of 140 keV, which is optimal for gamma camera and SPECT imaging. This energy provides high image quality while minimizing radiation dose to the patient.
- Technetium-99m has a relatively short physical half-life of approximately 6.01 hours, which is long enough to perform diagnostic imaging procedures yet short enough to limit radiation exposure.
- It is readily available in clinical practice through a convenient <sup>99</sup>Mo/<sup>99m</sup>Tc generator, where molybdenum-99 decays by beta-minus emission to produce technetium-99m on site in nuclear medicine departments.
- In addition, technetium-99m exhibits favorable chemical properties, allowing it to be easily labeled with a wide variety of pharmaceutical kits, which enables imaging of multiple organs such as the bone, heart, kidneys, lungs, liver, and brain.

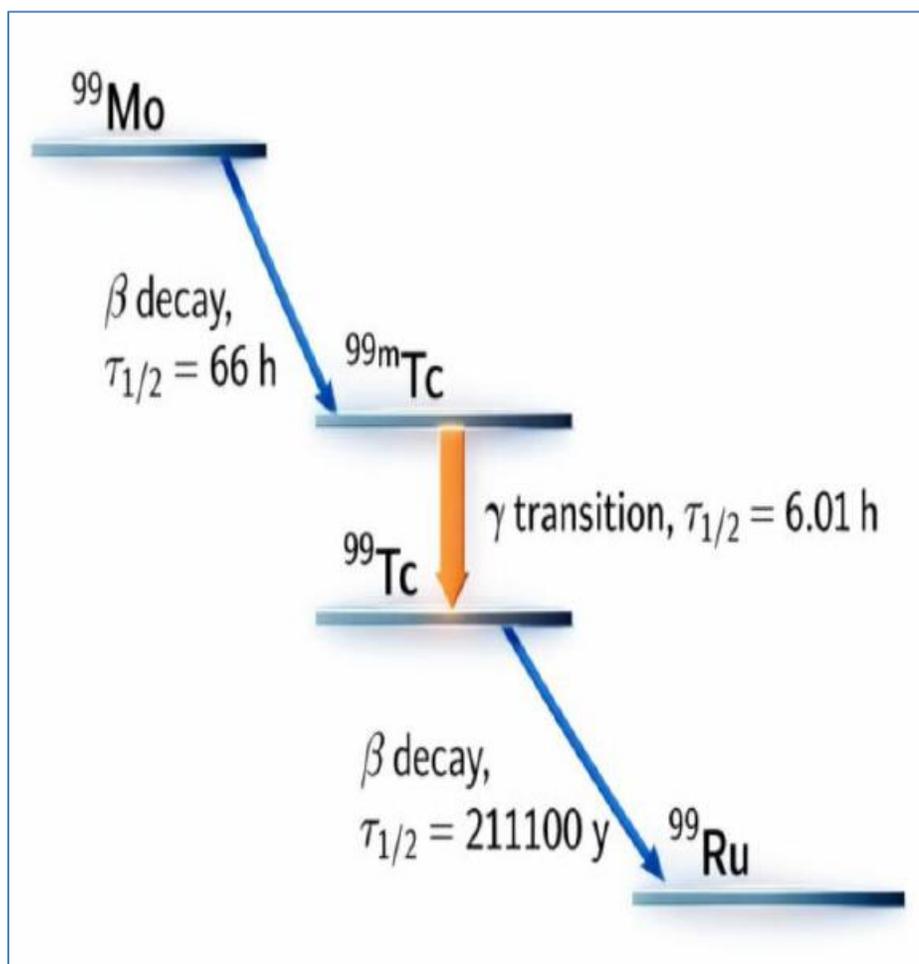
The decay scheme shown in the slide represents the production and decay of technetium-99m used in diagnostic nuclear medicine:

### **1. Molybdenum-99 (<sup>99</sup>Mo) decays by beta-minus ( $\beta^-$ ) decay**

with a half-life of approximately 66 hours, producing technetium-99m. This process occurs inside the technetium generator.

**2. Technetium-99m (<sup>99m</sup>Tc) is a metastable nuclear state.** It decays by isomeric transition, emitting a 140 keV gamma\_photon with a half-life of 6.01 hours. This gamma emission is responsible for image formation in gamma cameras and SPECT systems.

3. After gamma emission, technetium-99m transforms into **technetium-99 ( $^{99}\text{Tc}$ )**, which decays very slowly by beta-minus decay to **stable ruthenium-99 ( $^{99}\text{Ru}$ )** with a half-life of approximately 211,000 years. Due to this extremely long half-life, technetium-99 has no significant impact on patient dosimetry but is relevant for radioactive waste considerations.



## Radiopharmaceutical Production

Radiopharmaceuticals are radioactive compounds used in nuclear medicine for diagnostic imaging and targeted therapy. Their production involves two essential stages:

### 1. Production of the Radionuclide

The radionuclide is the radioactive component responsible for radiation emission. It can be produced using the following methods:

- Nuclear reactors: Radionuclides are produced either by nuclear fission or by neutron activation, where stable nuclei absorb neutrons and become radioactive.
- Cyclotrons: Stable target materials are bombarded with positively charged particles such as protons or deuterons to produce radionuclides commonly used in medical imaging and therapy.

## **2. Radiolabeling Process**

After production, the radionuclide is chemically combined with a pharmaceutical compound. This process, known as radiolabeling, allows the radioactive substance to selectively target specific organs, tissues, or disease sites within the body.

### **Clinical Application**

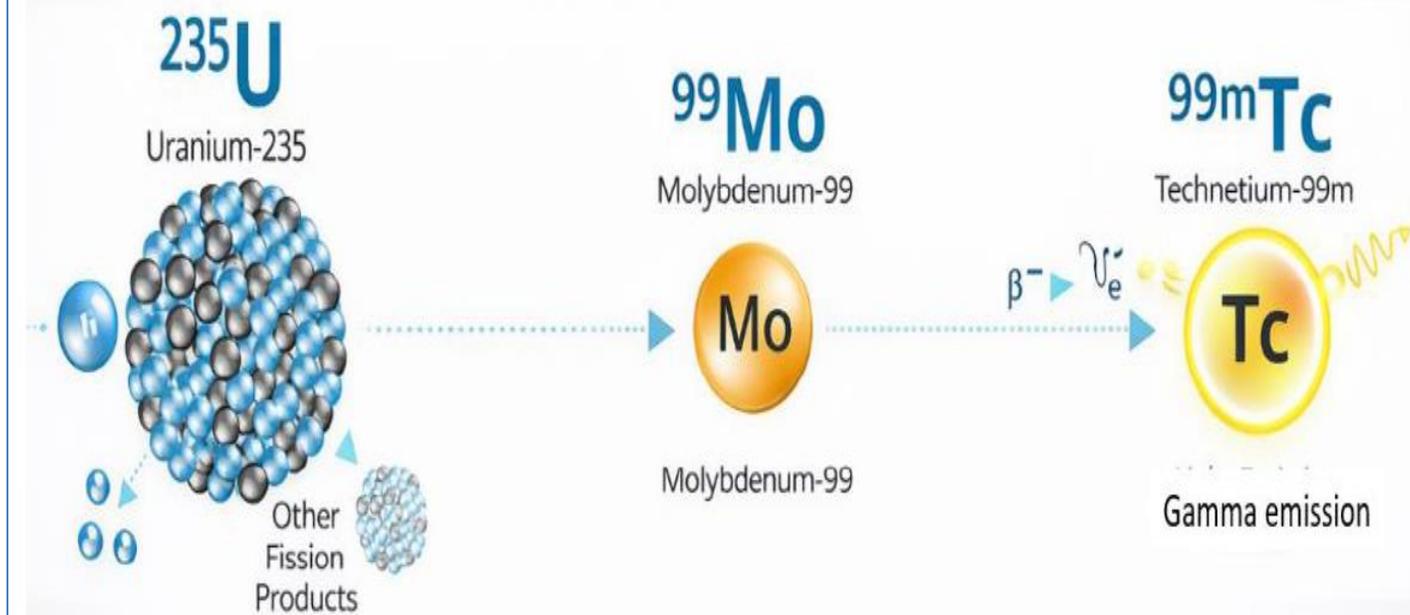
Diagnostic radiopharmaceuticals are used to visualize organ function and detect disease. Therapeutic radiopharmaceuticals deliver localized radiation to destroy diseased cells while minimizing damage to healthy tissue.

	Availability	Cost	Typical Radionuclides
Fission Products	High	Low	$^{99}\text{Mo}$ / $^{99}\text{Tc}$
Nuclear Reactor	Moderate	Moderate	$^{60}\text{Co}$ , $^{131}\text{I}$ ,...
Cyclotron	Moderate	High	$^{18}\text{F}$ , $^{11}\text{C}$ ,...

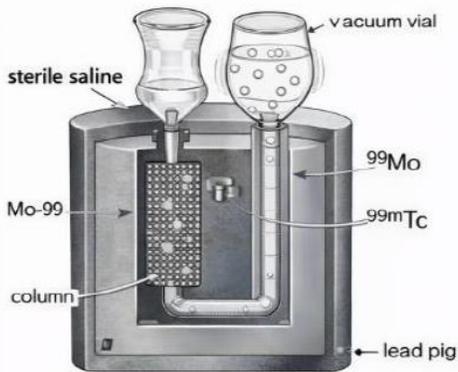
Fig below explain Molybdenum-99 is produced in nuclear reactors via uranium-235 fission, whereas technetium-99m is generated locally in hospitals using a  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$  generator. Diagnostic imaging relies exclusively on the gamma emission of technetium-99m.

## Example of Production of Technetium-99m

- Uranium-235 is bombarded with neutrons, causing **nuclear fission**, which produces **Molybdenum-99** along with other fission products.
- **Molybdenum-99** undergoes **beta ( $\beta^-$ ) decay** to form **Technetium-99m**, which is a **metastable** radionuclide.
- **Technetium-99m** then decays by emitting **gamma radiation**, which is used for diagnostic imaging in nuclear medicine.



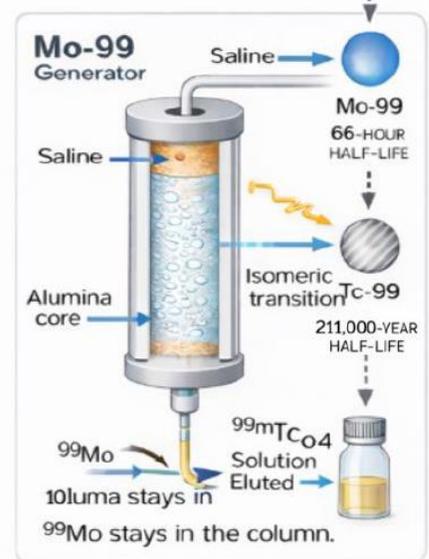
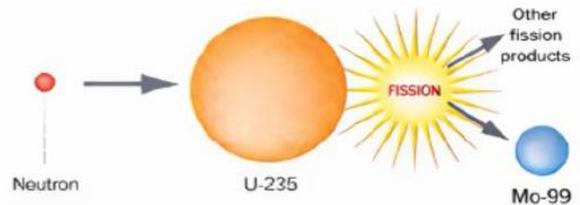
# Technetium Generator



- Generators are devices that allow separation of a daughter radionuclide from the parent in a shielded container that may be transported long distances from the manufacturing site (reactor or accelerator).
- Most commercial  $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$  generators use column chromatography, in which  $^{99}\text{Mo}$  in the form of molybdate,  $\text{MoO}_4^{2-}$  is adsorbed onto acid alumina ( $\text{Al}_2\text{O}_3$ ). When the Mo-99 decays it forms pertechnetate  $\text{TcO}_4^-$ , which, because of its single charge, is less tightly bound to the alumina.
- Pouring normal saline solution through the column of immobilized  $^{99}\text{Mo}$  elutes the soluble  $^{99\text{m}}\text{Tc}$ , resulting in a saline solution containing the  $^{99\text{m}}\text{Tc}$  as the pertechnetate.

## $^{99}\text{Molybdenum}$

- Is produced in a nuclear reactor as fission fragments and chemically separated (chapter 4).
- Has a 66 hour half life which allows it to be transported long distances.
- It decays to  $^{99\text{m}}\text{Tc}$  via isomeric transition, emitting gamma rays, which then decays to  $^{99}\text{Tc}$  with a very long half life.
- Is loaded into an alumina column where it releases  $^{99\text{m}}\text{Tc}$  in the form of sodium pertechnetate ( $^{99\text{m}}\text{TcO}_4$ ) when saline is run through the column.
- $^{99}\text{Mo}$  stays in the column.



# Some Medical Radionuclides

Element	Isotope	Emission	Energy(MeV) of Gamma	Half- Life	Decay Mode	Production
Technetium	$^{99m}\text{Tc}$	Gamma	0.140	6h	IT	Generator
Thallium	$^{201}\text{Tl}$	Gamma	0.80 & 0.167	73h	EC	Cyclotron
Gallium	$^{67}\text{Ga}$	Gamma	0.093 & 0.184 0.296	78h	EC	Cyclotron
Indium	$^{111}\text{In}$	Gamma	0.173 & 0.247	2.8d	EC	Cyclotron
Iodine	$^{123}\text{I}$	Gamma	0.159	13.3h	EC	Cyclotron
Iodine	$^{131}\text{I}$	Gamma	0.364	8d	$\beta^-$	Fission
Fluorine	$^{18}\text{F}$	Positron	0.511	109min	EC, $\beta^+$	Cyclotron
Carbon	$^{11}\text{C}$	Positron	0.511	20min	EC, $\beta^+$	Cyclotron
Nitrogen	$^{13}\text{N}$	Positron	0.511	10min	EC, $\beta^+$	Cyclotron
Oxygen	$^{15}\text{O}$	Positron	0.511	2min	EC, $\beta^+$	Cyclotron
Gallium	$^{68}\text{Ga}$	Positron	0.511	68min	EC, $\beta^+$	Generator
Rubidium	$^{82}\text{Rb}$	Positron	0.511	75sec	$\beta^+$	Generator
Xenon	$^{133}\text{Xe}$	Beta&Gamma	0.080	5.2d	$\beta^-$	Fission
Krypton	$^{81m}\text{Kr}$	Gamma	0.190	13sec	IT	Generator

## Study of Ventilation

- Ventilation studies in nuclear medicine are used to evaluate the distribution of air within the lungs and are commonly performed as part of ventilation/perfusion (V/Q) imaging.
- Ultrafine aerosols such as Technegas, which consists of carbon nanoparticles labeled with Technetium-99m (Tc-99m), are

widely used for ventilation imaging. Due to their extremely small particle size, these aerosols can reach the alveoli efficiently and provide a uniform representation of pulmonary ventilation.

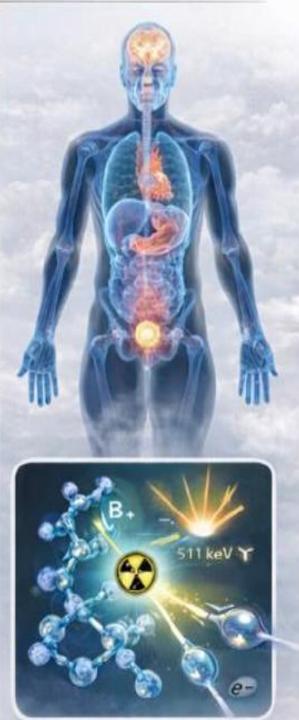
- Alternatively, radioactive noble gases such as Xenon-133 or Krypton-81m may be inhaled to assess airflow and gas distribution within the lungs.
- Ventilation imaging evaluates the flow of air, while perfusion imaging evaluates the flow of blood within the pulmonary circulation. Perfusion studies are typically performed using Tc-99m-labeled macroaggregated albumin (Tc-99m MAA), which becomes temporarily trapped in the pulmonary capillaries in proportion to regional blood flow.
- By comparing ventilation and perfusion images, clinicians can identify ventilation–perfusion mismatches, which are characteristic of conditions such as pulmonary embolism, where ventilation is preserved but perfusion is reduced.
- V/Q imaging remains an effective and reliable diagnostic technique, particularly in patients for whom CT pulmonary angiography is contraindicated.



# Tracers

Positron-emitting tracers labeled with carbon, nitrogen, oxygen and fluorine isotopes are commonly used in PET imaging due to their ability to emit positrons.

Isotope	Tracer Compound	Physiological Process or Function
$^{11}\text{C}$	Methionine	Protein synthesis
$^{11}\text{C}$	Flumazenil	Benzodiazepine receptor antagonist
$^{11}\text{C}$	Raclopride	D2 receptor antagonist
$^{13}\text{N}$	Ammonia	Blood perfusion
$^{15}\text{O}$	Carbon dioxide	Blood perfusion
$^{15}\text{O}$	Water	Brain activation studies
$^{18}\text{F}$	Fluoro-deoxy-glucose (FDG)	Oncology, neurology, cardiology
$^{18}\text{F}$	Fluoride ion	Oncology, oncology
$^{18}\text{F}$	Fluoro-misonidazole	Oncology - response to radiotherapy



These tracers are commonly used in PET imaging due to positron emission.

## Oncologic imaging

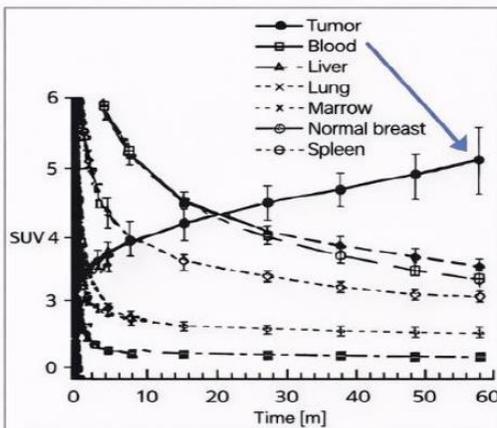
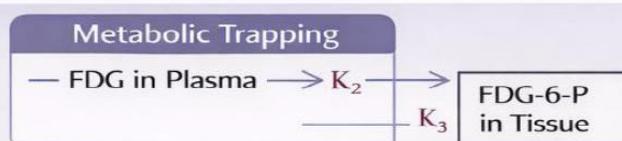
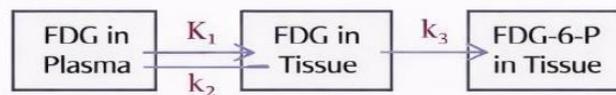


FIGURE 1. Mean time-activity curves (+ s.e.m.) for tumor and normal tissues in 18 women with untreated primary breast cancer. On average, tumor activity increased as a function of time relative to blood and normal tissues through 60 min.

In FDG-PET, tumors show increasing activity over time due to increased metabolic trapping of FDG in cancer cells.

**Increased metabolism** → increased accumulation of activity over time (increased trapping)

- ◆ Tumors show increasing FDG uptake over time compared to normal tissues
- ◆ FDG moves from plasma into tissues ( $k_1$ )
- ◆ FDG becomes "trapped" in cells by metabolic trapping ( $k_3$ )



In FDG-PET, tumors show increasing activity over time due to increased metabolic trapping of FDG in cancer cells.