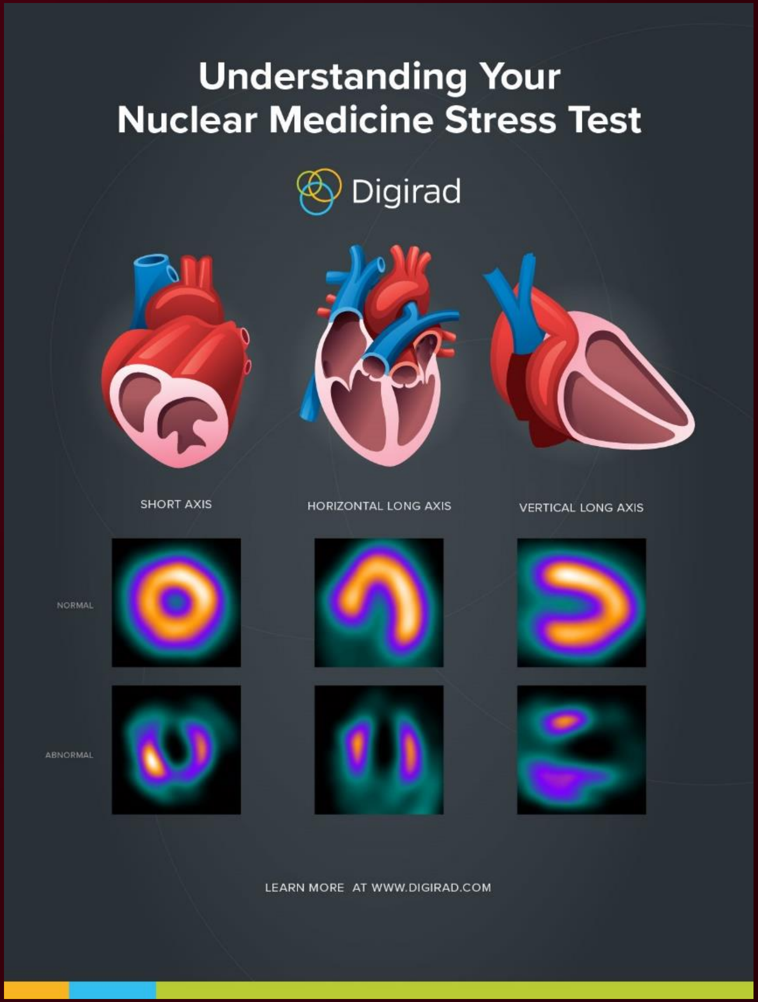
# *The nuclear science behind nuclear medicine*

FSU PANAMA CITY

CENTER FOR EXCELLENCE
CENTAUR
IN NUCLEAR TRAINING AND UNIVERSITY-BASED RESEARCH

THE FLORIDA STATE UNIVERSITY

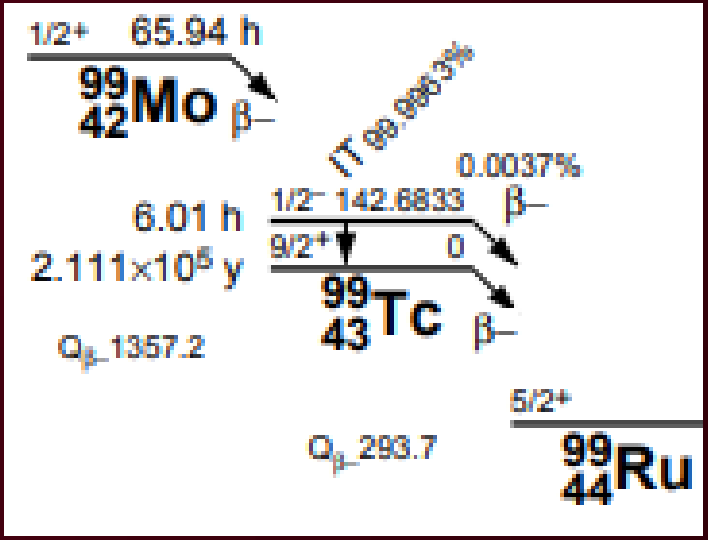
In a nuclear stress test, the isotope $^{99m}Tc$ is put into a syringe and then injected into the blood stream, where it migrates to the heart and then radioactively decays by the emission of a gamma-ray so that it can be seen by a "gamma camera".

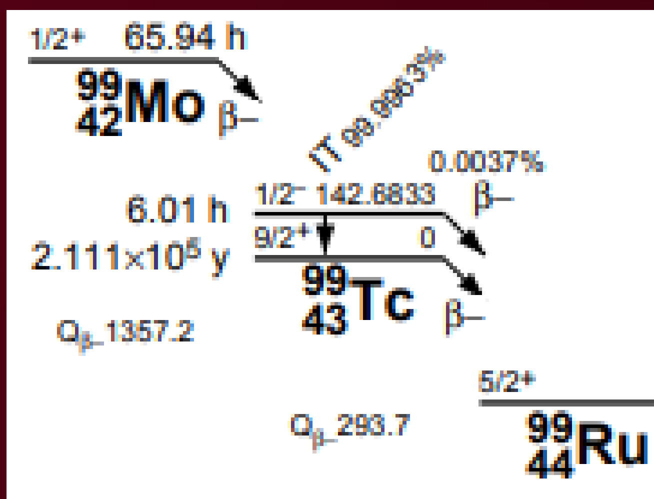

THE FLORIDA STATE UNIVERSITY

## What do we mean by “gamma-rays” and why does $^{99m}$Tc emit them?
## (And what does that little “m” mean?)

At the level of the very small, the science of quantum mechanics rules.  And in quantum mechanics, there are quantum states of different energies…



When an atomic nucleus (or any quantum state) changes from a state at a higher energy to a state at a lower energy, it emits a packet of electromagnetic radiation called a "photon". That packet carries a very specific amount of energy equal to the difference in energies of the two states.

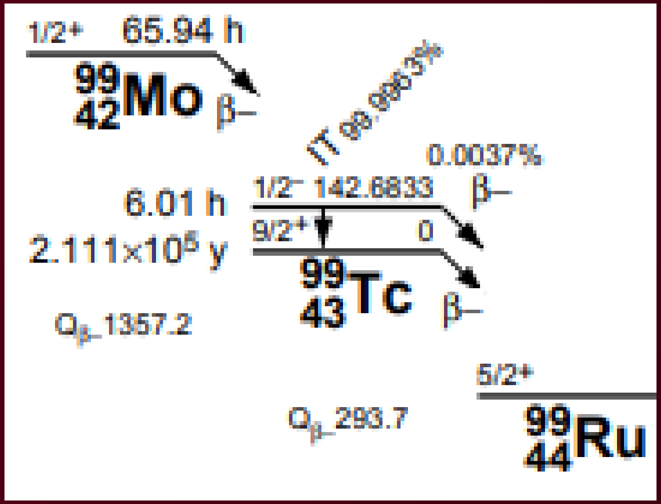



The keV, or kiloelectron volt, is a unit of energy often used in nuclear science.

1 keV = $1.60 \times 10^{-16}$ Joules,

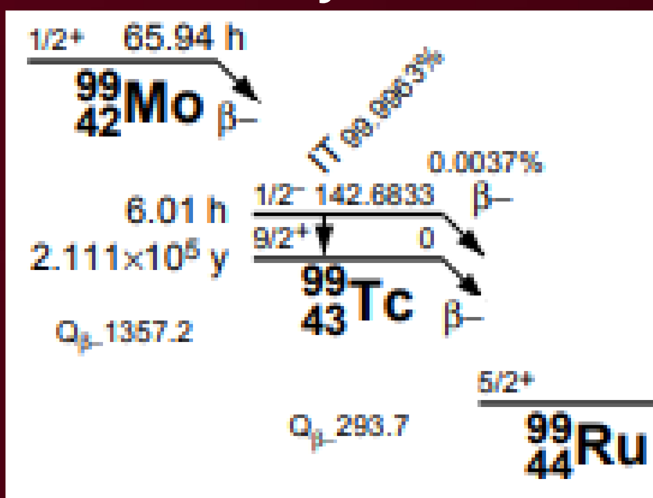
So 142 keV = $2.28 \times 10^{-14}$ Joules

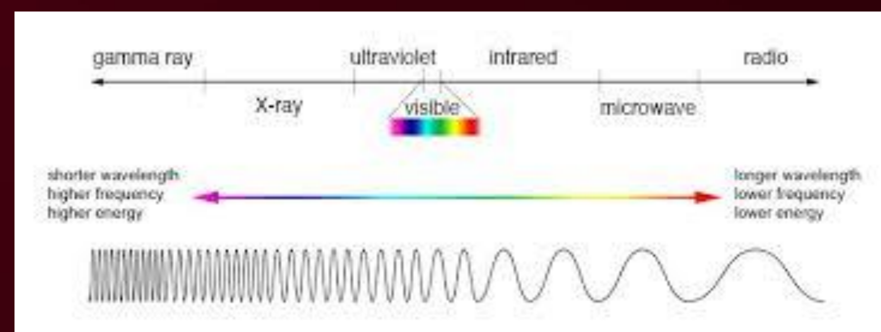
The “m” in $^{99m}$Tc stands for the higher energy state in $^{99}$Tc – the 142 keV state that emits the 142 keV gamma-ray that allows medical physicists to take a picture of the blood flow in the heart.



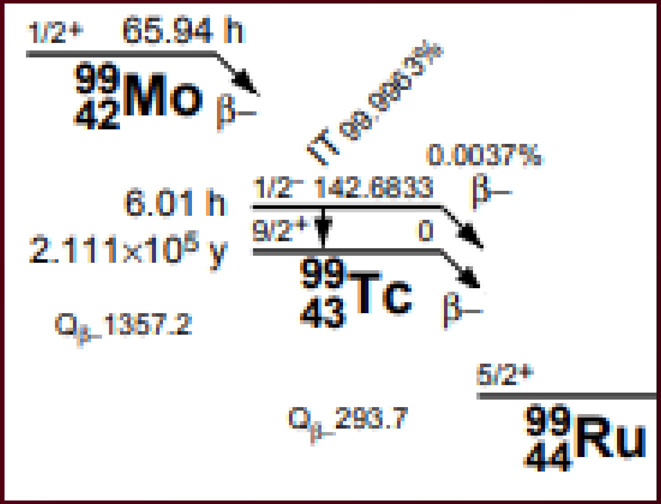

The way to make $^{99m}$Tc is through a different sort of radioactive decay – the beta-decay of $^{99}$Mo.

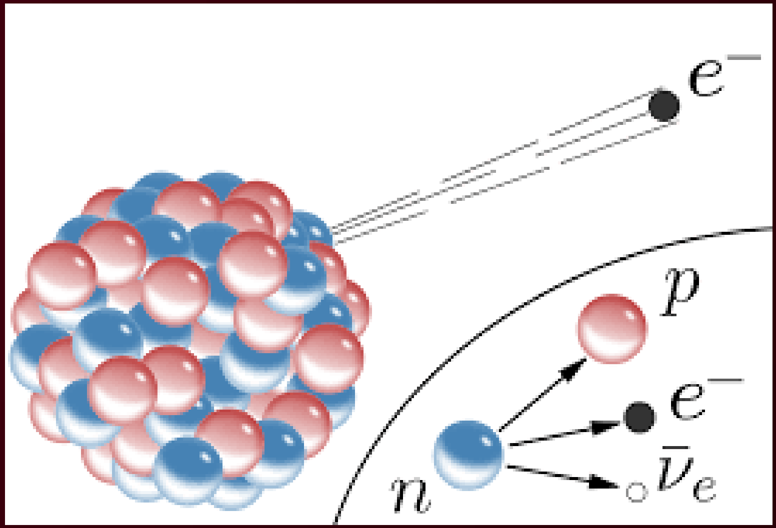
Electromagnetic radiation includes everything from the radio waves that a radio receives to gamma-rays – what we call the “electromagnetic spectrum”.  The hydrogen atom emits visible light photons in some of its quantum transitions.  Nuclei have much larger quantum state energies than atoms, so they emit gamma-ray photons, which carry much more energy than visible light photons.



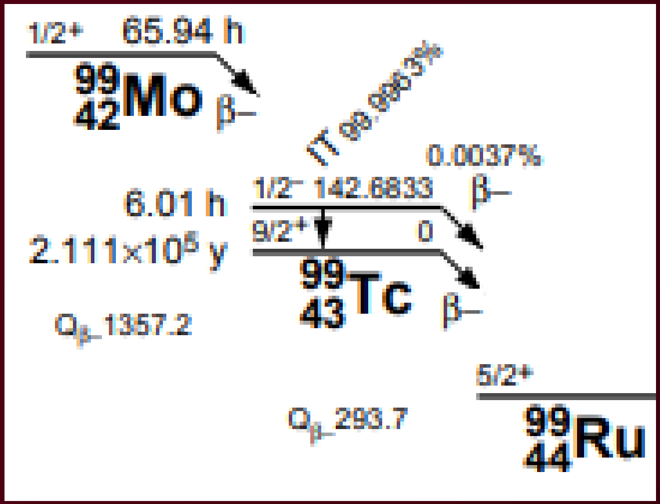
In beta-decay, a neutron in the nucleus decays into three particles – a proton, an electron, and a ghostly particle called a neutrino.

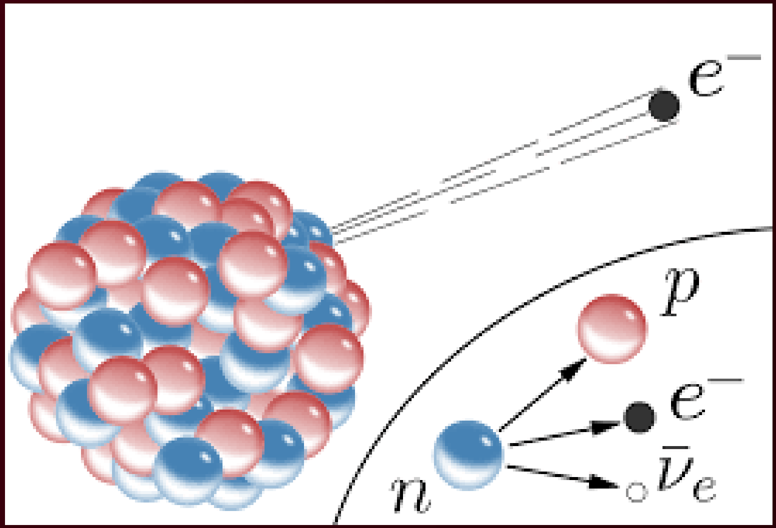


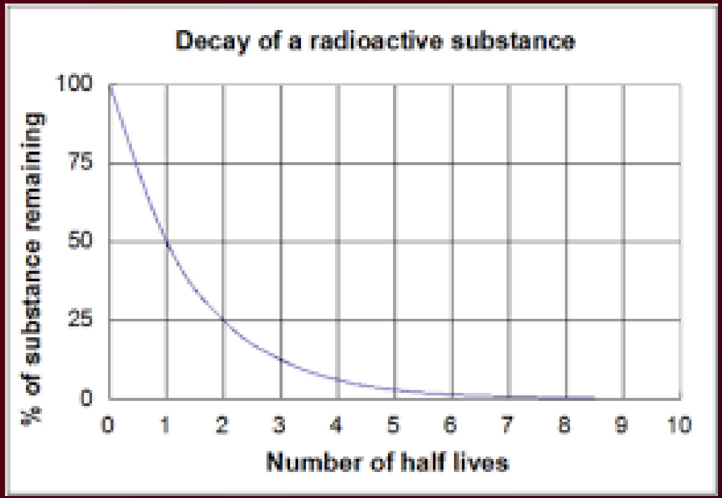
$^{}$Beta-decay only happens in isotopes that have too many neutrons to be stable. The stable isotopes of Mo are $^{92}$Mo, $^{94}$Mo, $^{95}$Mo, $^{96}$Mo, $^{97}$Mo and $^{98}$Mo.

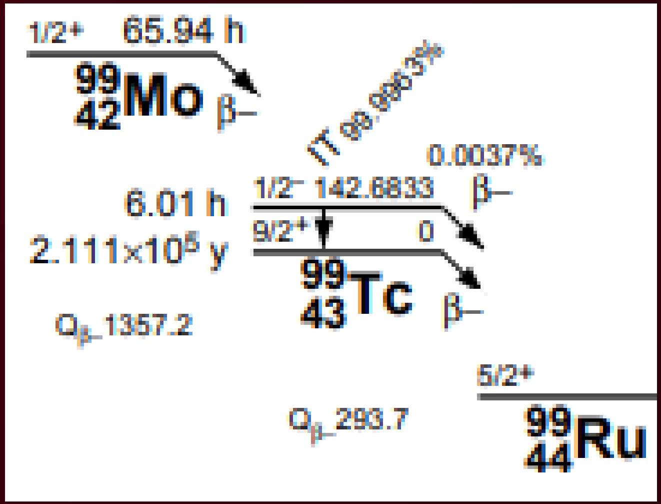
$^{99}$Mo has a much longer “half-life” than $^{99m}$Tc, so $^{99}$Mo is produced at a few nuclear reactors in the world and then shipped to nuclear medicine facilities.



The half-life is the amount of time it takes for half of an amount of a radioactive isotope to decay. We will spend more time on this concept later today. But for now, notice that the half-life of $^{99m}Tc$ is only 6 hours – too short for any sort of long distance travel. But $^{99}Mo$ has a half-life of 66 hours – almost three days.



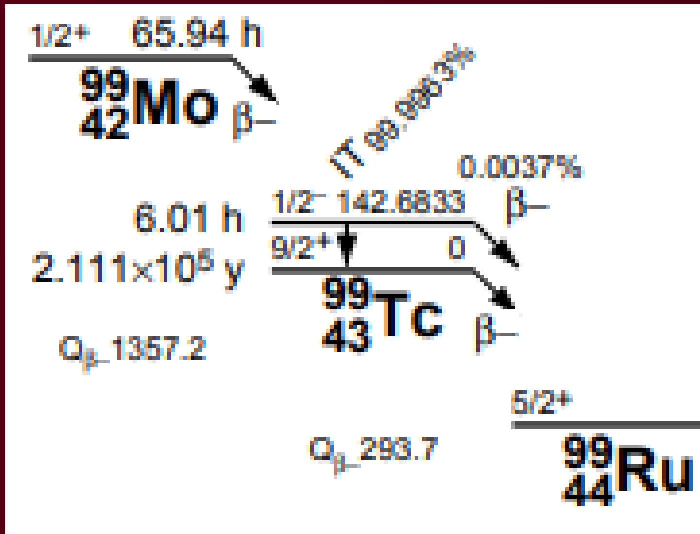
# Production of $^{99}Mo$ takes place at nuclear reactors equipped for that purpose, none of which are located in North America.

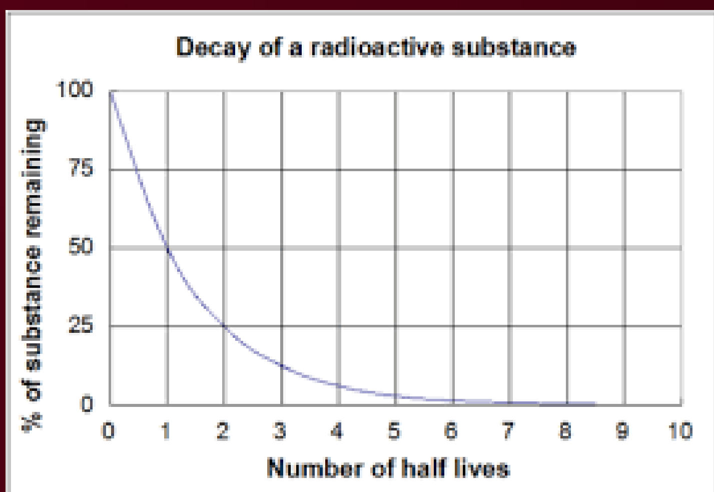
Petten,
The Netherlands

**Molybdenum Production Facility**

In this facility, Molybdenum irradiated in the High Flux Reactor is prepared for transport to hospitals. From here, medical isotopes make their way to patients within and outside Europe.

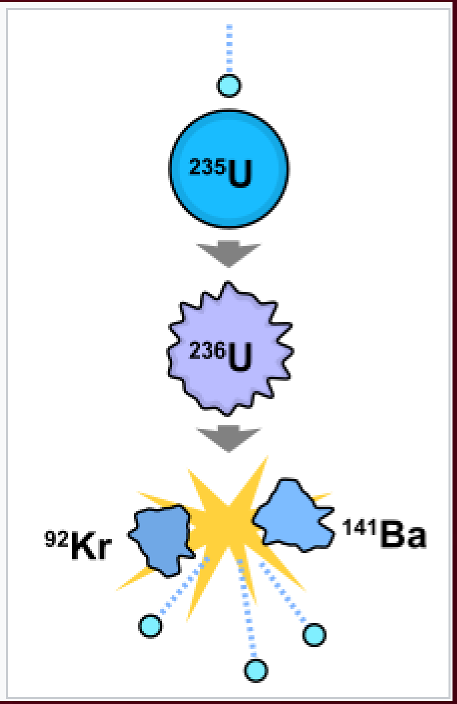

THE FLORIDA STATE UNIVERSITY




**How much of the $^{99}$Mo produced in the Netherlands radioactively decays during an 8-hour flight from Amsterdam to Atlanta?**

## The $^{99}Mo$ is produced by a reaction in which a neutron is absorbed by a $^{235}U$ nucleus which then fissions.




When a nucleus of $^{99}Mo$ is produced in such a reaction, the other nucleus produced is an isotope of Sn.

Why?

U has 92 protons.
Mo has 42 protons.
So the other resulting nucleus must have 50 protons – Sn.

National Nuclear Security Administration

# NNSA awards cooperative agreements for the production of molybdenum-99 to three U.S. companies

JULY 22, 2019



## VITAL MEDICAL ISOTOPE IS USED IN OVER 40,000 MEDICAL PROCEDURES IN THE UNITED STATES EACH DAY

**WASHINGTON** – The Department of Energy's National Nuclear Security Administration (DOE/NNSA) has completed negotiations for three cooperative agreement awards for the production of molybdenum-99 (Mo-99) without the use of highly enriched uranium (HEU). These awards were