Clinically Useful Radionuclides

INTRODUCTION

It is important that Nuclear Medicine Technologists be familiar with the imaging properties of all commonly used radionuclides to insure correct choice of isotope for a particular study as well as to use the appropriate radiation safety precautions based on type and energy of emission.

While the majority of all Nuclear Medicine scans (~85%) are performed with Tc-99m, there are a number of other useful radioisotopes with which both diagnostic and therapeutic procedures are performed.

It is important to recognize the value of each of these isotopes and to know the physical half-life and principal imaging photon energy of the more important ones.

- This tutorial is designed to provide the viewer with a comprehensive overview of commercially available radionuclides and the technical information associated with each. In particular, half-life, principal imaging photon, and the method of production of each radionuclide are presented along with the decay scheme indicating the mode of decay as well as every important emission from the nuclide. The isotopes are presented in alphabetical order.

In some of the charts below, one will encounter the term % Abundance. Although our first thought might be that this represents the percent abundance in the earth's crust, in fact, % abundance is defined as the number of photons emitted per 100 disintegrations.

CLINICALLY USEFUL RADIONUCLIDES: Chromium-51 (Cr-51)

An important isotope for performing *in vivo* non-imaging procedures involving the radiolabeling of red blood cells is Cr-51. The technical information is presented in the chart below.

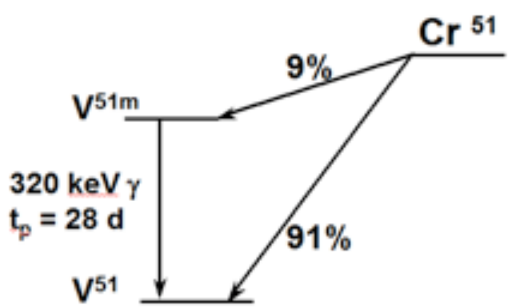
Nuclide	t_{phys}	γ-ray energy	% Abundance
Cr-51	28 days	320 KeV	9

Clinical Utility of Radioisotope: Radiolabeling of red blood cells for specialized *in vivo/in vitro* studies

Method of Production of Cr-51: Cyclotron

Mode of Decay: Electron Capture

Decay Scheme of Cr-51:



An excellent question would be the following:

When Cr-51 decays, only 9% of all disintegrations produce the 320-keV photon; why is the total 9% and not 100%?

The answer is evident from the decay scheme above, which illustrates the Electron Capture decay of Cr-51. The decay scheme indicates that 91% of the time, Cr-51 decays directly to the ground state of the V-51 daughter of Cr-51, bypassing the excites state and emitting no gamma rays at all. Only 9% of the time does Cr-51 decay directly to the excited state of the daughter (V-51m), which then further decays by Isomeric Transition to the ground state, emitting a 320 keV gamma ray during the process. Gamma rays are emitted from a nucleus only when a metastable state is involved and isomeric transition takes place.

We define a metastable state as an excited state with a measurable half-life.

CLINICALLY USEFUL RADIONUCLIDES: Fluorine-18

FLUORINE-18 (F-18) One of the most important radioisotopes in use today is F-18. The molecule F-18 fluorodeoxyglucose (FDG), a sugar analog, is used predominantly in oncology for malignant tumor imaging. As indicated below, it has a 110 min half-life and an energy of 511 keV.

Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
F-18	110 minutes	511	180

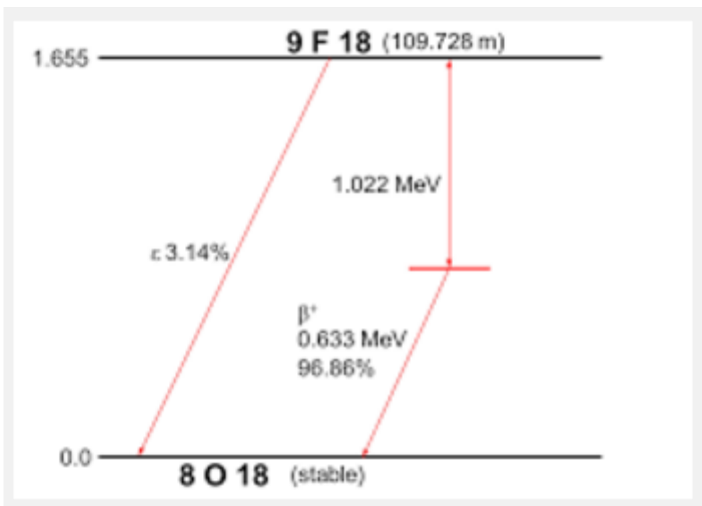
Oncologic Clinical Utility of Radioisotope: Imaging of malignant tumors; intense uptake represents sites of hypermetabolism as measured by accumulation of FDG, a sugar analog.

Cardiologic Utility: Imaging of hibernating myocardium

Method of Production of F-18: Cyclotron

Mode of Decay: 97% Positron Emission and 3% Electron Capture

Decay Scheme of F-18



F-18 decays predominantly by positron emission. Positrons annihilate electrons in matter and result in the formation of 2 gamma rays, always 180^{o} apart and always 511 keV in energy. The theoretical maximum % abundance is 200% since two gamma rays are emitted per positron. As indicated above, 180% reflects a process that is 90% efficient.

CLINICALLY USEFUL RADIONUCLIDES: Gallium-67

GALLIUM-67 (Ga-67) is no longer commonly used in most labs. The physical properties are shown below. Typically, an energy window is set to include the 94 and 184 keV photons only; the 296 keV photon energy is not within the ideal energy range of 100 – 250 keV and is therefore undesirable.

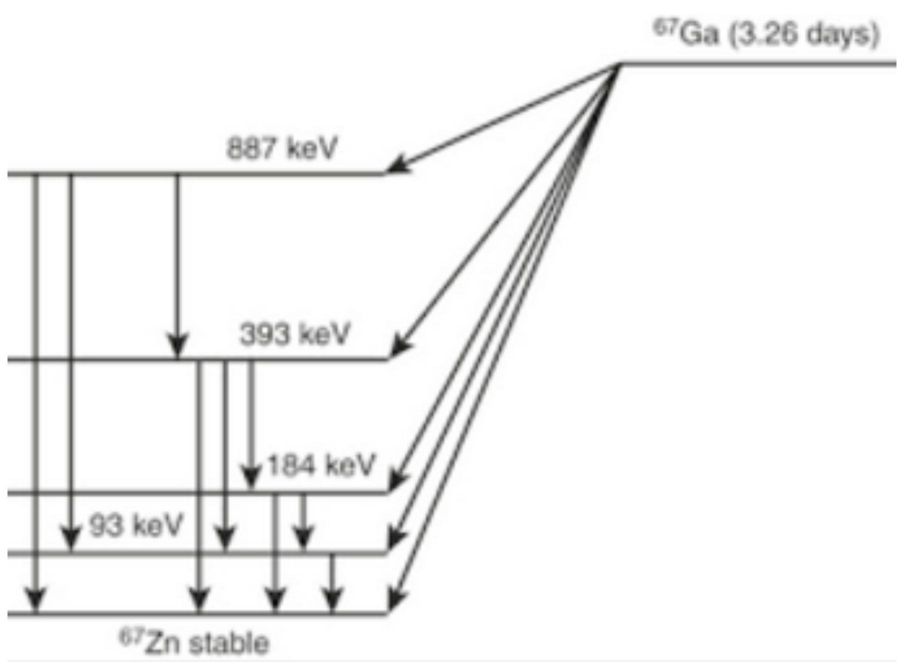
Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
Ga-67	79.2 hr	94	40
		184	24
		296	22

Clinical Utility of Radioisotope: Imaging of malignant tumors as well as abscesses and inflammatory sites

Method of Production of Ga-67: Cyclotron

Mode of Decay: Electron Capture

Decay Scheme of Ga-67



CLINICALLY USEFUL RADIONUCLIDES: Radioiodine Isotopes

I-123, I-125, and I-131 are three radioisotopes of Iodine currently used in Nuclear Medicine.

1. I-123 is used for diagnostic studies
2. I-131 is commonly used for both diagnostic and therapeutic studies.
3. I-125 is occasionally used today for plasma volume studies as well as for basic research. It is important historically as it was the most common isotope used in Radioimmunoassays.

They are listed in the chart below.

Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
I-123	13.3 hr	159	83
I-125	60 d	35 gamma, 28 x-ray	140
I-131	8.08 d	364.4	82

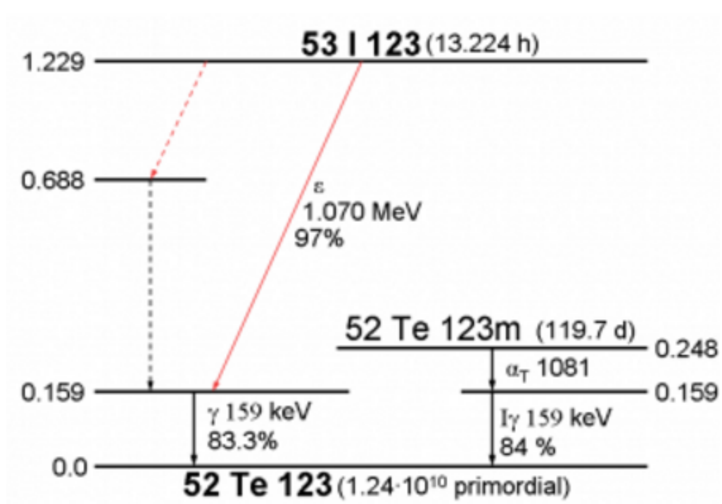
IODINE 123 (I-123), with its ideal energy (159 keV) and its 13.3 hr half-life, is an excellent imaging isotope and can be bound easily to many different molecules.

Clinical Utility of I-123: Imaging of thyroid when in the chemical form of NaI; of neuroendocrine tumors when in chemical form of mIBG

Method of Production of I-123: Cyclotron

Mode of Decay: Electron Capture

Decay Scheme of I-123



IODINE 125 (I-125)

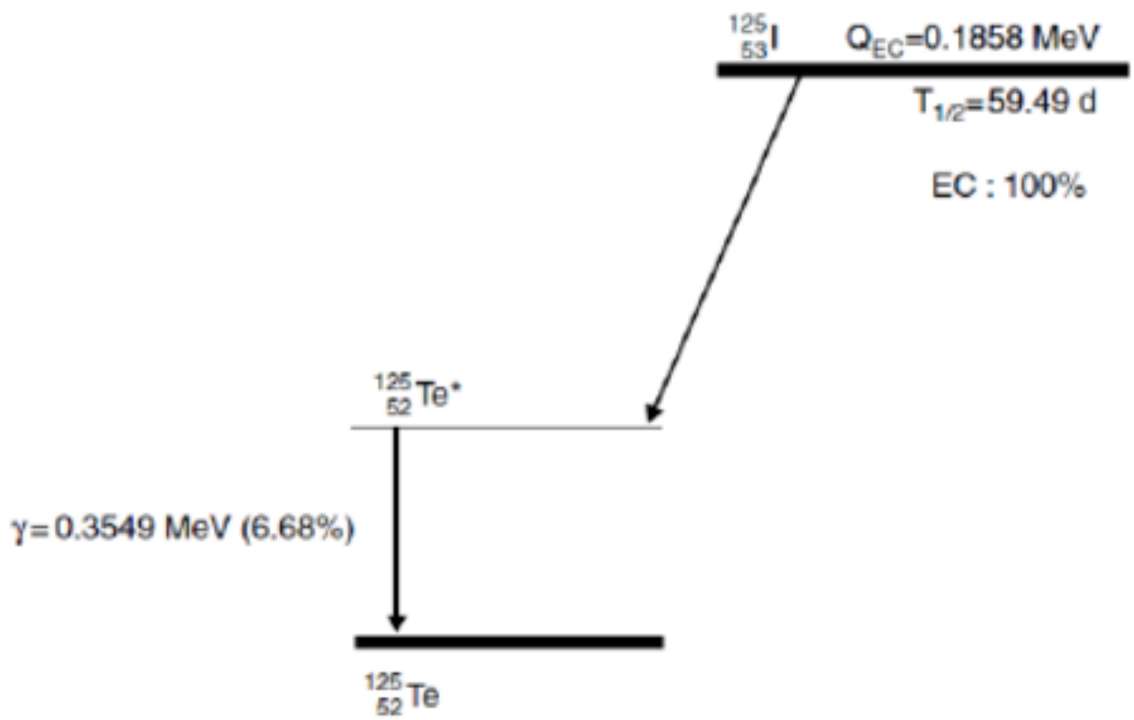
Clinical Utility of I-125: Performance of plasma volume studies for determining presence of polycythemia in patients

Method of Production of I-125: ^{125}I is a reactor-produced radionuclide and is available in large quantities. Its production utilizes the following reaction:

$$^{124}Xe\ (n,\gamma) \rightarrow\ ^{125m}Xe(57s) \rightarrow\ ^{125}I\ (59.4\ d)$$

Mode of Decay: Electron Capture

Decay Scheme of I-125:



IODINE 131 (I-131)

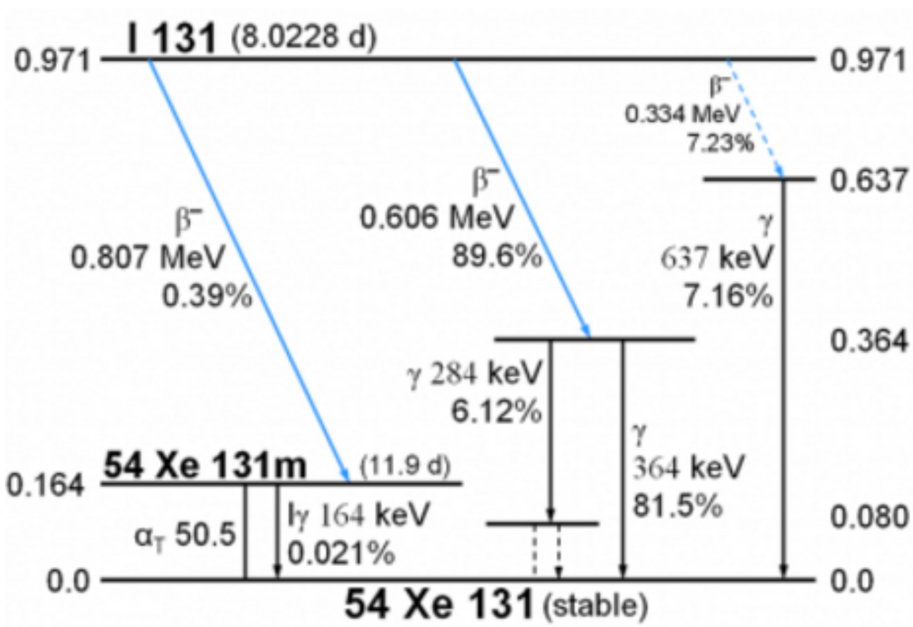
I-131, which emits both betas and gammas, is utilized for both diagnosis and therapy and is one of the first radioisotopes ever administered to humans. Radionuclide therapy for hyperthyroidism was first performed in the mid-1940s using I-131 NaI..

Clinical Utility of I-131: When in the chemical form of NaI, may be used for whole body metastatic survey for thyroid Ca, thyroid scan in patient with substernal thyroid, or therapy for hyperthyroidism or thyroid Ca.

Method of Production of I-131: Fission of U-235

Mode of Decay: Beta minus

Decay Scheme of I-131:



Question: Which gamma ray in the decay scheme of I-131 displayed above is the one that we use for imaging?

Answer: There is a gamma ray on the right side of the decay scheme indicating an energy of 364 KeV and a percent abundance of 81.5%. From the base of the arrow to the tip of the arrow, the energy differential is 364 KeV

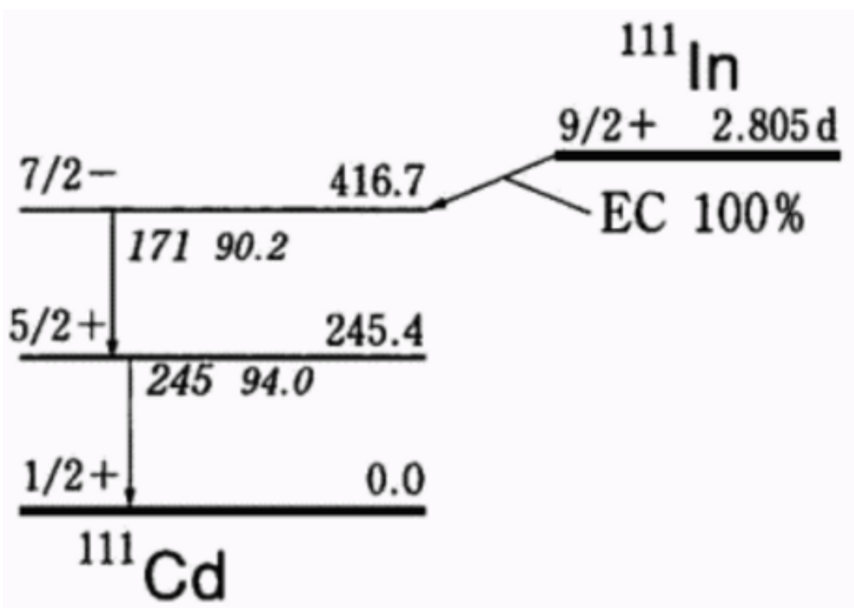
CLINICALLY USEFUL RADIONUCLIDES: Indium-111

In-111, a very expensive isotope (> $100/mCi), is typically bound to antibodies, polypeptides, or white blood cells for diagnostic studies. In-111 has two usable photons in the ideal imaging energy range, 173 keV and 247 keV, both in very high % abundance.

Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
In-111	67 hr	173 247	89 94

How is it possible to have 183% abundance for the 2 photons emitted by In-111? In-111 is not a positron emitter with a possible 200% abundance. The answer may be discerned from the decay scheme below:

Decay scheme of In-111



In this case, there is a highly excited metastable state of the daughter as well as an intermediate excited state. Since all transitions go through both states with very high abundance, more than 180 photons in total are emitted per 100 disintegrations. In no case does In-111 decay directly to the ground state.

CLINICALLY USEFUL RADIONUCLIDES: Molybdenum-99 (Mo-99)

Mo-99 is the parent of all Tc-99m prepared in the world for medical use. Shielding of Mo-99 is difficult due to the very high-energy photons emitted by this radioisotope. Even though the percent abundance for each is relatively low, Curie quantities are often present following an elution during the early life of the generator.

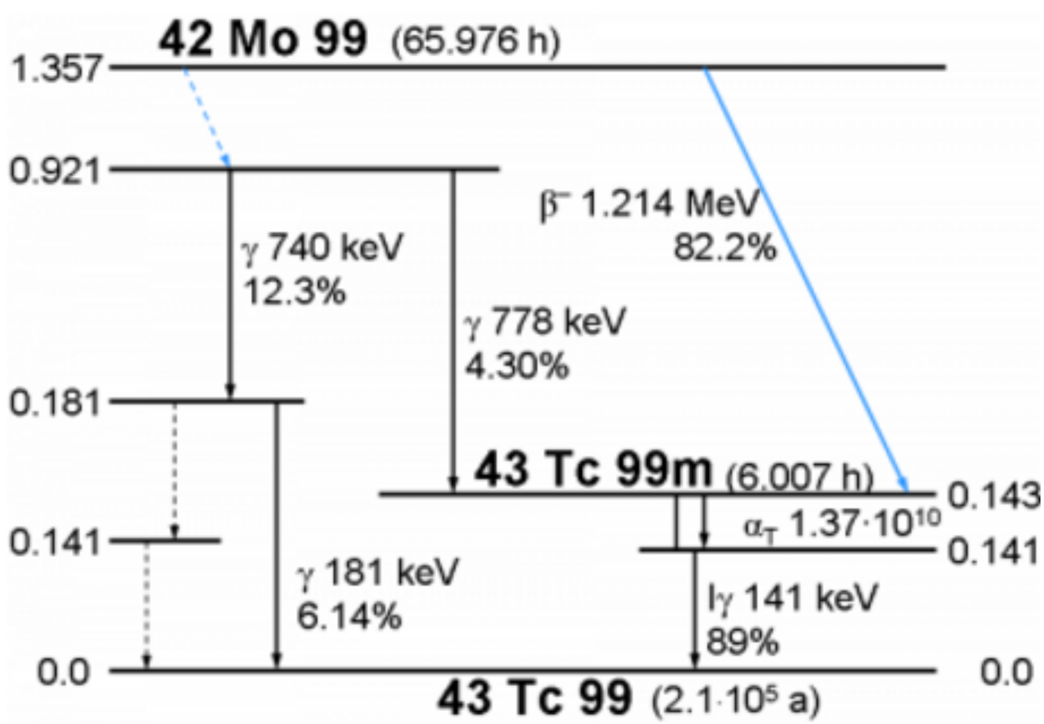
Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
Mo-99	67 h	181 740 780	6 12 4

Clinical Utility of Radioisotope: Production of Tc-99m in a generator. Mo-99 is NEVER knowingly injected into patients.

Method of Production of Mo-99: Fission of U-235

Mode of Decay: Beta Minus

Decay Scheme of Mo-99:



CLINICALLY USEFUL RADIONUCLIDES: Rubidium-82 (Rb-82)

This radioisotope has become increasingly popular for Cardiac PET studies due to the availability of both the Sr-82/Rb-82 Generator and PET scanners, now present in most hospitals.

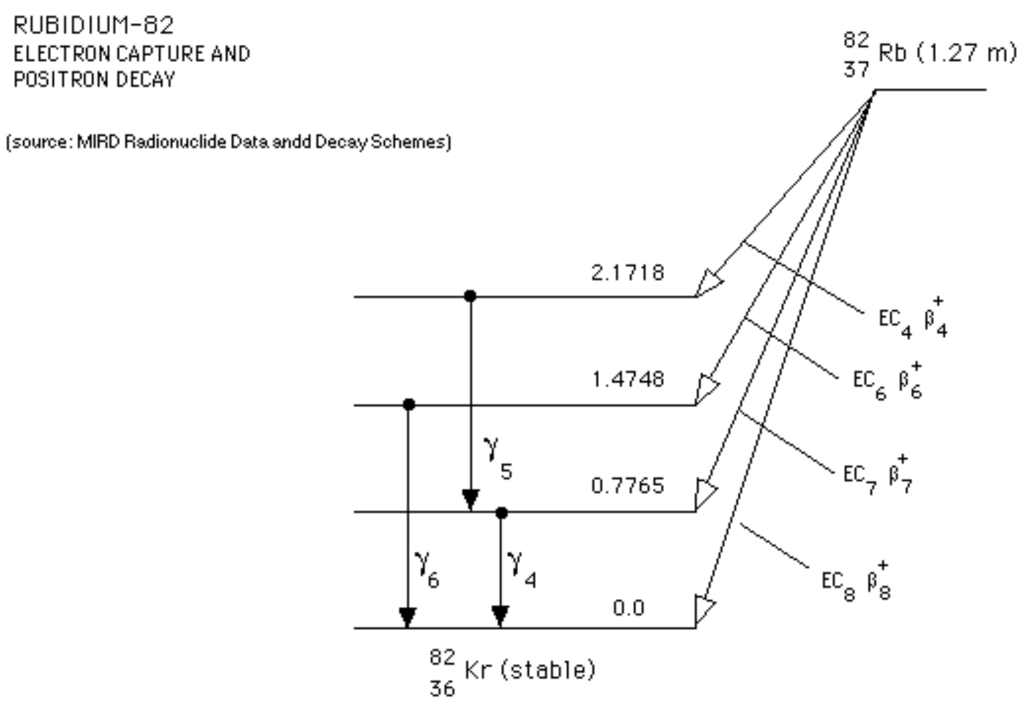
Nuclide	t_{phys}	γ–ray energy (keV)	% Abundance
Rb-82	75s	511	190

Clinical Utility of Radioisotope: Imaging of myocardial perfusion using a potassium analog.

Method of Production of Rb-82: Sr-82/Rb-82 generator

Mode of Decay: Positron Emission

Decay Scheme of Rb-82



% abundance issue:

% abundance could theoretically be 200% since 2 annihilation photons are emitted per decay. The process is only 95% efficient, so percent abundance is 190%.

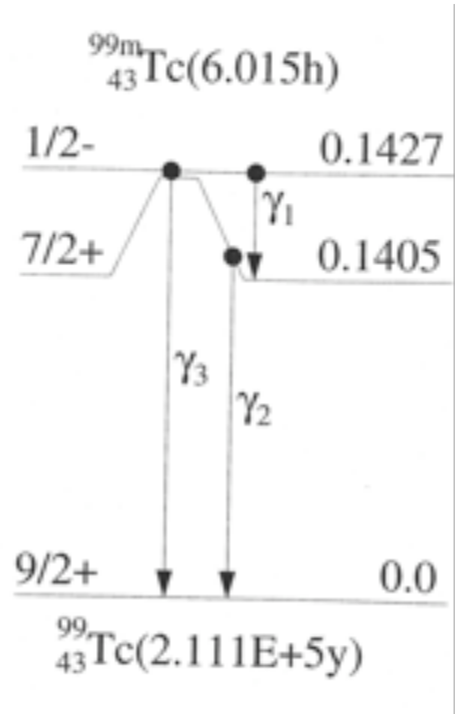
CLINICALLY USEFUL RADIONUCLIDES: Technetium-99m (Tc-99m)

Tc-99m, the so-called “Workhorse of Nuclear Medicine”, accounts for approximately 85% of all scans performed in the US and in the world. Its ideal imaging energy, ready availability, very favorable radiation dosimetry, ease of radiolabeling, and reasonable cost ($1.00/mCi) make it the perfect radioisotope for diagnostic imaging studies.

Tc-99m is the only element in the periodic table under # 82 that has never been found in nature- there are no stable isotopes of Tc-99m and it is therefore a synthetic isotope.

Nuclide	t_{phys}	γ –ray energy (keV)	% Abundance
Tc-99m	6.02h	140.5	90

The decay scheme:



Output data

Radiation	% abundance	Energy (MeV)
Gamma-1	0.00	0.0021
M-ICE, γ1	98.6	0.0017
Gamma-2	86.3	0.1405
K-ICE, γ2	8.63	0.1195
L-ICE, γ2	1.09	0.1377
M-ICE, γ2	0.36	0.1401
Gamma-3	0.03	0.1427
K-ICE, γ3	0.96	0.1217
L-ICE, γ3	0.30	0.1300
M-ICE, γ3	0.10	0.14213
Kα1 X-rays	4.30	0.0184
Kα2 X-rays	2.16	0.0183
Kβ1 X-rays	1.03	0.0206
Kβ2 X-rays	0.18	0.0210
L X-rays	0.81	0.0024
KLL Auger electrons	1.49	0.0155
KLX Auger electrons	0.55	0.0178
KXY Auger electrons	0.07	0.0202
LMM Auger electrons	10.6	0.0019
MXY Auger electrons	123	0.0004

CLINICALLY USEFUL RADIONUCLIDES: Thallium-201 (Tl-201)

Tl-201, known mostly for cardiac imaging, is also useful for diagnosing parathyroid adenomas as well as the most malignant brain tumors, for which there are almost no false-positive studies. Tl-201 emits 2 gamma rays of ideal energy (135 and 167 keV), but the % abundance of each is very low; we therefore rely mostly on the Hg-201 X-rays for imaging. While the energy of the X-rays (71-80 keV) is suboptimal, the abundance is very high. The quality of Tl-201 images is typically inferior to that of Tc-99m images.

Nuclide	t_{phys}	γ –ray energy (keV)	% Abundance
Tl-201	73h	135 167 (and 71 Hg X-rays)	2 8

% abundance issue:

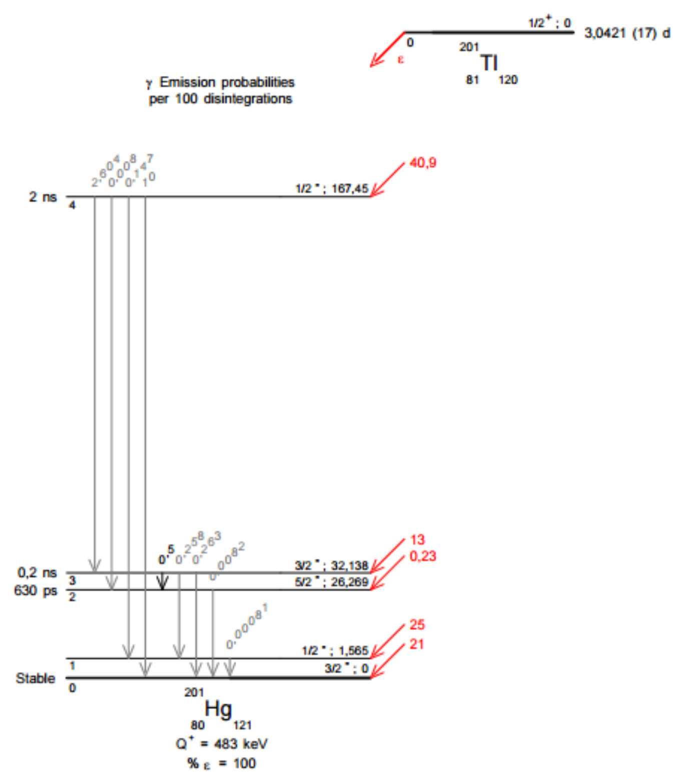
The 135 and 167 keV gamma-rays are ideal for imaging, but total % abundance is just 10%. We choose to use the X-rays of Hg-201, Tl-201's daughter, because the % abundance is very high, even though the 71 keV energy of the X-rays is suboptimal.

Clinical Utility of Radioisotope: Imaging of myocardial perfusion using a potassium analog.

Method of Production of Tl-201: Cyclotron

Mode of Decay: Electron Capture

Decay Scheme of Tl-201



CLINICALLY USEFUL RADIONUCLIDES: Xe-133 (Xe-133)

This isotope is administered most often as a gas for pulmonary ventilation studies, but can be dissolved in saline for specialized blood-flow studies.

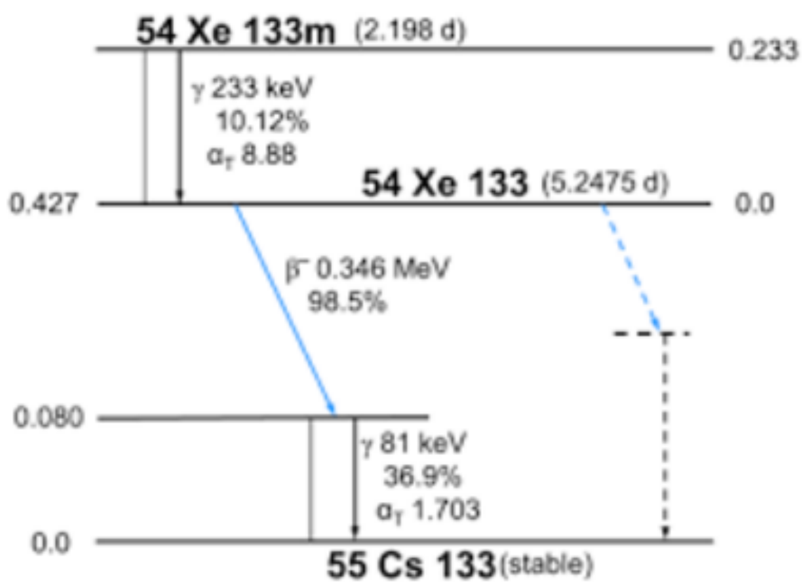
Nuclide	t_{phys}	g –ray energy (keV)	% Abundance
Xe-133	5.3 d	81	37

Clinical Utility of Radioisotope: Pulmonary ventilation studies.

Method of Production of Xe-133: Fission of U-235

Mode of Decay: Beta Minus

Decay Scheme of Xe-133



% abundance issue: % abundance is only moderate at 37%, but radiation dose from Xe-133 is low due to the very short effective half-life, so we can compensate by giving 20-30 mCi for the ventilation study, compared to 3 mCi for the perfusion scan.

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