

C H A P T E R 1

Radioisotopes

Not for Distribution

TABLE 1-1 Radiopharmaceuticals Used in Nuclear Medicine

| Radionuclide | Chemical Form and Dosage Form | Use | Typical Dosage (Adult)* | Route ^b |
|----------------|----------------------------------|---|-------------------------|--------------------|
| Carbon C 11 | Carbon monoxide | Cardiac: Blood volume measurement | 60–100 mCi | Inhalation |
| Carbon C 11 | Flumazenil injection | Brain: Benzodiazepine receptor imaging | 20–30 mCi | IV |
| Carbon C 11 | Methionine injection | Neoplastic disease evaluation in brain | 10–20 mCi | IV |
| Carbon C 11 | Raclopride injection | Brain: Dopamine D ₂ receptor imaging | 10–15 mCi | IV |
| Carbon C 11 | Sodium acetate injection | Cardiac: Marker of oxidative metabolism | 12–40 mCi | IV |
| Carbon C 14 | Urea | Diagnosis of <i>Helicobacter pylori</i> infection | 1 μ Ci | PO |
| Chromium Cr 51 | Sodium chromate injection | Labeling red blood cells (RBCs) for measuring RBC volume, survival, and splenic sequestration | 10–80 μ Ci | IV |
| Cobalt Co 57 | Cyanocobalamin capsules | Diagnosis of pernicious anemia and defects of intestinal absorption | 0.5 μ Ci | PO |
| Fluorine F 18 | Fludeoxyglucose injection | Glucose utilization in brain, cardiac, and neoplastic disease | 10–15 mCi | IV |
| Fluorine F 18 | Fluorodopa injection | Dopamine neuronal decarboxylase activity in brain | 4–6 mCi | IV |
| Fluorine F 18 | Sodium fluoride injection | Bone imaging | 10 mCi | IV |
| Gallium Ga 67 | Gallium citrate injection | Hodgkin's disease, lymphoma Acute inflammatory lesions | 8–10 mCi 5 mCi | IV IV |
| Indium In 111 | Capromab pentetide injection | Metastatic imaging in patients with biopsy-proven prostate cancer | 5 mCi | IV |
| Indium In 111 | Indium chloride sterile solution | Radiolabeling various ¹¹¹ In radiopharmaceuticals | Various | Various |

| | | | | |
|---------------|-------------------------------------|---|---|-------------|
| Indium In 111 | Indium oxine sterile solution | Labeling autologous leukocytes | 500 µCi | IV |
| Indium In 111 | Pentetate injection | Cisternography | 500 µCi | Intrathecal |
| Indium In 111 | Pentetreotide injection | Neuroendocrine tumors | 3 mCi (planar) 6 mCi (SPECT ^c) | IV |
| Indium In 111 | Ibritumomab tiuxetan injection | Biodistribution imaging prior to therapeutic dosing with ⁹⁰ Y Zevalin (Biogen Idec) in the treatment of non-Hodgkin's lymphoma | 5 mCi | IV |
| Iodine I 123 | Ioflupane Injection | Striatal dopamine transporter visualization (assist in the evaluation of adult patients with suspected Parkinsonian syndrome) (PS) | 3–5 mCi | IV |
| Iodine I 123 | Sodium iodide capsules and solution | Thyroid gland imaging | 400–600 µCi | PO |
| Iodine I 123 | Iobenguane injection | Thyroid metastases (total body) | 2 mCi | PO |
| Iodine I 125 | Albumin injection | Pheochromocytoma, carcinoid tumors, non-secreting paragangliomas, neuroblastoma | 0.14 mCi/kg (child) 10 mCi (adult) | IV |
| Iodine I 125 | Iothalamate sodium injection | Plasma volume determination | 5–10 µCi | IV |
| Iodine I 131 | Albumin injection | Glomerular filtration rate (GFR) determination | 30 µCi | IV |
| Iodine I 131 | Iobenguane injection | Blood volume/plasma volume determination | 5–50 µCi | IV |
| Iodine I 131 | Sodium iodide capsules and solution | Pheochromocytoma, carcinoid tumors, non-secreting paragangliomas, neuroblastoma | 0.5 mCi/1.7m ² | IV |
| Iodine I 131 | Sodium iodide capsules and solution | Thyroid function | 5–10 µCi | PO |
| | | Thyroid imaging (neck) | 50–100 µCi | |
| | | Thyroid imaging (substernal) | 100 µCi | |
| | | Thyroid metastases (total body) | 2 mCi | |
| | | Hyperthyroidism | 5–33 mCi | |
| | | Carcinoma | 150–200 mCi | |

(continued)

TABLE 1-1 Radiopharmaceuticals Used in Nuclear Medicine (Continued)

| Radionuclide | Chemical Form and Dosage Form | Use | Typical Dosage (Adult ^a) | Route ^b |
|-------------------|--------------------------------|--|--|--|
| Iodine I 131 | Iodohippurate sodium injection | Recoverable renal function | 200 μ Ci (2 kidneys) 75 μ Ci (1 kidney) | IV |
| Iodine I 131 | Tositumomab | Treatment of refractory low-grade non-Hodgkin's lymphoma | Patient-specific dosing; not >75 cCy whole body | IV |
| Nitrogen N 13 | Ammonia injection | Myocardial perfusion studies | 10–20 mCi | IV |
| Oxygen O 15 | Water injection | Cardiac perfusion | 30–100 mCi | IV |
| Phosphorus P 32 | Chromic phosphate suspension | Peritoneal and pleural effusions | 10–20 mCi | Intraperitoneal or intrapleural (Not for IV use) |
| Phosphorus P 32 | Sodium phosphate injection | Polycythemia | 1–8 mCi | IV |
| Rubidium Rb 82 | Rubidium chloride injection | Myocardial perfusion studies | 30–60 mCi | IV |
| Samarium Sm 153 | Lexidronam injection | Bone pain palliation in confirmed osteoblastic metastatic bone lesions | 1.0 mCi/kg | IV |
| Strontium Sr 89 | Strontium chloride injection | Bone pain palliation in confirmed osteoblastic metastatic bone lesions | 4 mCi | IV |
| Technetium Tc 99m | Albumin injection | Heart blood pool imaging | 20 mCi | IV |
| Technetium Tc 99m | Albumin aggregated injection | Perfusion lung imaging | 3 mCi | IV |

| | | | | |
|-------------------|---------------------------|--|-----------|----|
| Technetium Tc 99m | Arcitumomab | Recurrent or metastatic colorectal carcinoma | 20 mCi | IV |
| Technetium Tc 99m | Bicisate injection | Adjunct to CT/MRI ^d in patients with confirmed stroke | 20 mCi | IV |
| Technetium Tc 99m | Disofenin injection | Hepatobiliary imaging | 5 mCi | IV |
| Technetium Tc 99m | Exametazime injection | With or without methylene blue for regional cerebral perfusion in stroke | 20 mCi | IV |
| | | Without methylene blue for leukocyte labeling | 10 mCi | IV |
| Technetium Tc 99m | Glucelate injection | Brain imaging | 20 mCi | IV |
| | | Renal perfusion imaging | 10 mCi | IV |
| Technetium Tc 99m | Mebrofenin injection | Hepatobiliary imaging | 5 mCi | IV |
| Technetium Tc 99m | Medronate injection | Bone imaging | 20–30 mCi | IV |
| Technetium Tc 99m | Mertiatide injection | Kidney imaging | 5 mCi | IV |
| | | Renogram—renal transplant | 1–3 mCi | IV |
| | | Renogram—captopril | 1–3 mCi | IV |
| Technetium Tc 99m | Oxidronate injection | Bone imaging | 20–30 mCi | IV |
| Technetium Tc 99m | Pentetate injection | GFR (quantitative) | 3 mCi | IV |
| | | Renogram (diuretic) | 3 mCi | IV |
| | | Renal perfusion imaging | 10 mCi | IV |
| Technetium Tc 99m | Pyrophosphate injection | Infarct-avid scan | 15 mCi | IV |
| Technetium Tc 99m | Red blood cells injection | GI bleed (intermittent) | 15 mCi | IV |
| Technetium Tc 99m | Sestamibi injection | Myocardial perfusion and function, parathyroid imaging | 8–40 mCi | IV |

(continued)

TABLE 1-1 Radiopharmaceuticals Used in Nuclear Medicine (Continued)

| Radionuclide | Chemical Form and Dosage Form | Use | Typical Dosage (Adult ^a) | Route ^b |
|-------------------|--------------------------------|---|--|---|
| Technetium Tc 99m | Sodium pertechnetate injection | Brain imaging Thyroid imaging Radionuclide ventriculogram Radionuclide cystography Dacryocystography Meckel's diverticulum | 20 mCi 10 mCi 20 mCi 1 mCi 0.1 mCi 5 mCi | IV IV IV Urethral Eye drops IV |
| Technetium Tc 99m | Succimer injection | Renal scan—differential renal function Renal scan—cortical anatomy | 5 mCi 5 mCi | IV IV |
| Technetium Tc 99m | Sulfur colloid injection | Liver-spleen scan Lymphoscintigraphy (breast) Lymphoscintigraphy (melanoma) Gastric emptying (scrambled egg) GI bleed (acute) Lung aspiration Gastroesophageal reflux | 5 mCi 0.4–0.6 mCi 0.5–0.8 mCi 1 mCi 10 mCi 5 mCi 0.2 mCi | IV Interstitial Intradermal PO IV PO PO |
| Technetium Tc 99m | Tetrofosmin injection | Myocardial perfusion and function | 8–40 mCi | IV |
| Thallium Tl 201 | Thallous chloride injection | Myocardial perfusion imaging Parathyroid imaging | 3–4 mCi 2 mCi | IV IV |
| Xenon Xe 133 | Xenon | Lung ventilation imaging | 10–20 mCi | Inhalation |
| Yttrium Y 90 | Ibritumomab tiuxetan | Treatment of refractory low-grade non-Hodgkin's lymphoma | 0.3–0.4 mCi/kg | IV |

^a Except where otherwise noted.^b IV = intravenous; PO = oral.^c SPECT = single-photon emission computed tomography.^d CT = computed tomography; MRI = magnetic resonance imaging.

TABLE 1-2 Radionuclides in Nuclear Medicine

| Nuclide | Decay Mode ^a | Half-life ^a | β_{max} in MeV (% Intensity) ^{b,c} | β_{mean} (MeV) ^b | Photon MeV (γ and x-rays) (% Intensity) ^b | Half-Value Layer (mm Pb) | Gamma Ray Dose Constant (R/mCi-hr/cm) ^e |
|------------------|---------------------------|------------------------|--|--|--|--------------------------|--|
| ¹¹ C | β^+ | 20.3 min | 0.960 (100) | 0.386 | 0.511 (200) | 4.0 | 5.91 |
| ¹³ N | β^+ | 9.97 min | 1.198 (100) | 0.492 | 0.511 (200) | 4.0 | 5.91 |
| ¹⁴ C | β^- | 5700 yr | 0.156 (100) | 0.049 | None | None | None |
| ¹⁵ O | β^+ | 122 sec | 1.732 (100) | 0.735 | 0.511 (200) | 4.0 | 5.91 |
| ¹⁸ F | β^+ | 109.8 min | 0.633 (97) | 0.250 | 0.511 (193) | 4.0 | 5.73 |
| ³² P | β^- | 14.26 days | 1.710 (100) | 0.695 | None | None | None |
| ⁵¹ Cr | EC | 27.7 days | None | None | 0.320 (10) | 1.7 | 0.18 |
| ⁵⁷ Co | EC | 271.7 days | None | None | 0.122 (86) 0.136 (11) | 0.2 | 1.0 |
| ⁵⁸ Co | EC, β^+ | 70.9 days | 0.475 (15) | 0.201 | 0.811 (99) | 9.0 | 5.5 |
| ⁶⁴ Cu | EC, β^+ , β^- | 12.7 hr | β^+ 0.653 (17.6) | β^+ 0.278 | 0.511 (35.2) | 0.4 | 1.16 |
| | | | β^- 0.579 (38.5) | β^- 0.191 | | | |
| ⁶⁷ Cu | β^- | 61.8 hr | 0.168 (1) | 0.141 | 0.091 (7) | 7.0 | 0.52 |
| | | | 0.377 (57) | | 0.093 (16) | | |
| | | | 0.468 (22) | | 0.185 (49) | | |
| | | 0.562 (20) | | | | | |
| ⁶⁷ Ga | EC | 3.26 days | None | None | 0.093 (39) 0.185 (21) 0.300 (17) 0.394 (5) | 0.66 | 0.8 |
| ⁶⁸ Ga | β^+ | 67.7 min | 0.822 (1) | 0.830 | 0.511 (178) | 4.0 | 5.37 |
| | | | 1.899 (88) | | | | |

(continued)

TABLE 1-2 Radionuclides in Nuclear Medicine (Continued)

| Nuclide | Decay Mode ^a | Half-life ^b | β_{\max} in MeV (% Intensity) ^{b,c} | β_{mean} (MeV) ^b | Photon MeV (γ and x-rays) (% Intensity) ^b | Half-Value Layer (mm Pb) | Gamma Ray Dose Constant (R/mCi-hr/cm) ^e |
|-------------------|-------------------------|------------------------|---|--|--|-----------------------------|--|
| ⁸² Rb | β^+ | 76.4 sec | 2.60 (13) 3.38 (82) | 1.48 | 0.511 (191) 0.777 (15) | 7.0 | 6.1 |
| ^{81m} Kr | IT | 13.1 sec | None | None | 0.190 (68) | 0.019 | 1.6 |
| ⁸⁹ Sr | β^- | 50.5 days | 1.4926 (100) | 0.585 | None | None | None |
| ⁹⁰ Y | β^- | 64 hr | 2.28 (100) | 0.934 | None | None | None |
| ^{99m} Mo | β^- | 65.94 hr | 0.437 (16) 1.215 (82) | 0.389 | 0.740 (12) 0.778 (4) | 6.5 | 0.18 |
| ^{99m} Tc | IT | 6.02 hr | None | None | 0.1405 (89) | 0.17 | 0.78 |
| ⁹⁹ Tc | β^- | 2.11E+5 yr | 0.294 (100) | 0.085 | None | None | None |
| ¹¹¹ In | EC | 2.8 days | None | None | 0.023 (69), x-rays 0.026 (13), x-rays 0.171 (91) 0.245 (94) | 0.23 | 3.21 |
| ¹²³ I | EC | 13.22 hr | None | None | 0.027 (70), x-rays 0.030 (0.032 (15), x-rays 0.159 (83) | 0.05 | 1.6 |
| ¹²⁴ I | EC, β^+ | 4.18 days | 1.534 (12) 2.137 (11) | 0.820 | 0.027 (47), x-rays 0.511 (46) 0.603 (63) 0.723 (10) 1.691 (11) | 8.0 ^d | 7.6 ^d |

| ¹²⁵ I | EC | 59.4 days | None | None | 0.027 (114), x-rays 0.031–0.032 (24), x-rays 0.035 (7) | 0.017 | 1.43 |
|-------------------|----------------|-----------|--|-------|--|-------|------|
| ¹³¹ I | β ⁻ | 8.02 days | 0.248 (2) | 0.182 | 0.030 (5), x-rays | 2.4 | 2.27 |
| | | | 0.339 (7) | | 0.080 (3) | | |
| | | | 0.606 (90) | | 0.364 (82) 0.637 (7) | | |
| ¹³³ Xe | β ⁻ | 5.24 days | 0.346 | 0.100 | 0.031–0.036 (49), x-rays 0.081 (38) | 0.035 | 0.51 |
| ¹³⁷ Cs | β ⁻ | 30.08 yr | 0.514 (95) 1.175 (5) | 0.187 | 0.032 (6), x-rays 0.662 (85) | 6.0 | 3.32 |
| | | 46.5 hr | 0.635 (31) 0.704 (49) 0.808 (18) | 0.224 | 0.041 (48), x-rays 0.047 (9), x-rays 0.103 (29) | 0.1 | 0.46 |
| ¹⁶⁶ Re | β ⁻ | 3.72 days | 0.932 (22) 1.070 (71) | 0.347 | 0.137 (9) | 2.5 | 0.2 |
| ²⁰¹ Tl | EC | 3.04 days | None | None | 0.069–0.082 (75), x-rays 0.135 (26) 0.167 (10) | 0.006 | 4.7 |
| | | | | | | | |

^a EC = electron capture, IT = isomeric transition.

^b Values obtained from National Nuclear Data Center, Brookhaven National Laboratory (www.nndc.bnl.gov/chart/reCenter.jsp?z=39&η=51).

^c β_{max} is the endpoint energy for the decay.

^d Source: <http://hpschapters.org/northcarolina/NSDS/124IPDF.pdf>.

^e R = roentgen.

TABLE 1-3 Radionuclide Generator Systems

| Parent (half-life) | Parent Decay Mode | Daughter Product (half-life) | Column Type | Eluant |
|---------------------------------|-------------------|--|---------------------------|---------------------|
| ^{99}Mo (65.94 hr) | Beta minus | $\text{Na}^{99\text{m}}\text{TcO}_4$ (6.01 hr) | Aluminum oxide | 0.9% NaCl |
| ^{82}Sr (25.55 days) | Electron capture | $^{82\text{m}}\text{RbCl}$ (76.4 sec) | Stannic oxide | 0.9% NaCl |
| ^{68}Ge (271 days) | Electron capture | $^{68}\text{GaCl}_3$ (67.7 min) | Stannic oxide | 0.1 M HCl |
| ^{81}Rb (4.57 hr) | Electron capture | $^{81\text{m}}\text{Kr}$ gas (13.1 sec) | Cation exchange resin | Water Air/oxygen |
| ^{90}Sr (28.9 yr) | Beta minus | $^{90}\text{YCl}_3$ (64 hr) | ^{90}Sr solution | Solvent extraction |
| ^{113}Sn (115.09 days) | Electron capture | $^{113\text{m}}\text{InCl}_3$ (1.7 hr) | Zirconium oxide | 0.05 M HCl |

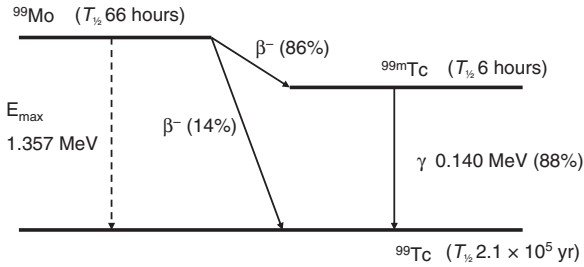


FIGURE 1-1 Simplified decay scheme for ^{99}Mo .

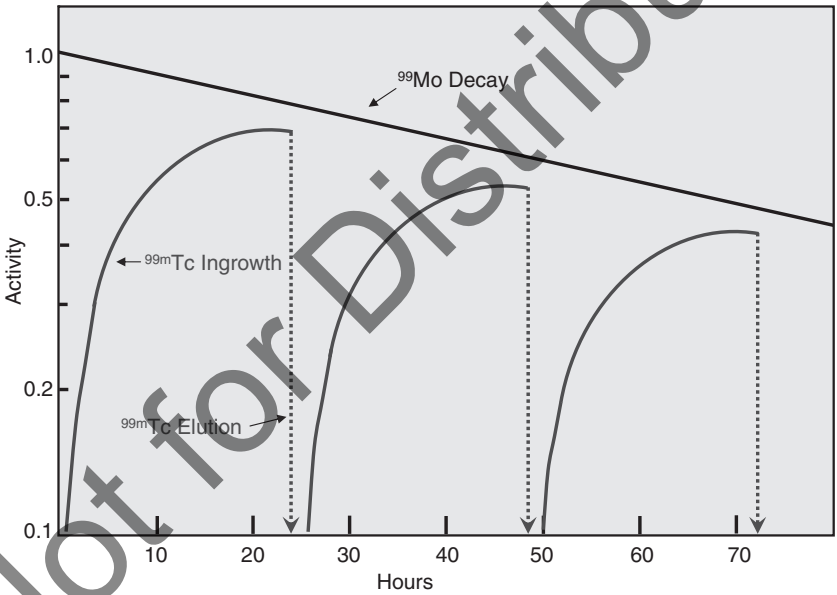


FIGURE 1-2 Decay of ^{99}Mo and ingrowth and elution of $^{99\text{m}}\text{Tc}$ activity over time in a $^{99\text{m}}\text{Tc}$ generator.

TABLE 1-4 Expiration Times for ^{99m}Tc -Sodium Pertechnetate after Generator Elution

| Initial Ratio (microcuries of ^{99}Mo /millicurie of ^{99m}Tc) | Expiration Time (hr) | Initial Ratio (microcuries of ^{99}Mo /millicurie of ^{99m}Tc) | Expiration Time (hr) |
|--|----------------------------|--|----------------------------|
| 0.135 | 1 | 0.072 | 7 |
| 0.122 | 2 | 0.065 | 8 |
| 0.109 | 3 | 0.058 | 9 |
| 0.098 | 4 | 0.052 | 10 |
| 0.089 | 5 | 0.047 | 11 |
| 0.080 | 6 | 0.042 | 12 |

Source: Ponto JA. Expiration times for Tc-99m. *J Nucl Med Technol.* 1981;9:40.

TABLE 1-5 Relationship between ^{99m}Tc and ^{99}Mo in the Generator at Various Times after Elution

| Time (hr) | Curies ^{99}Mo | \times Ratio $^{99m}\text{Tc} : ^{99}\text{Mo}$ | = | Curies ^{99m}Tc ^a |
|--------------|-------------------------|---|---|---------------------------------------|
| 0 | 1.000 | — | | 0 |
| 1 | 0.990 | 0.094 | | 0.093 |
| 2 | 0.979 | 0.179 | | 0.175 |
| 3 | 0.969 | 0.255 | | 0.247 |
| 4 | 0.959 | 0.324 | | 0.311 |
| 5 | 0.949 | 0.386 | | 0.366 |
| 6 | 0.940 | 0.441 | | 0.414 |
| 12 | 0.883 | 0.677 | | 0.598 |
| 18 | 0.829 | 0.803 | | 0.666 |
| 24 | 0.779 | 0.870 | | 0.678 |
| 36 | 0.688 | 0.924 | | 0.636 |
| 48 | 0.607 | 0.940 | | 0.571 |
| 60 | 0.533 | 0.944 | | 0.506 |
| 72 | 0.473 | 0.946 | | 0.448 |
| 78 | 0.445 | 0.946 | | 0.421 |

^a Actual ^{99m}Tc present based on 86.05% ^{99}Mo decay to ^{99m}Tc .