

Contents

<i>Chapter 1</i>	The Atom.....	1
	Electronic Structure of the Atom	1
	Chemical Bonds.....	2
	Electrovalent or Ionic Bond.....	4
	Covalent Bond.....	5
	Coordinate Covalent Bond	5
	Complex Formation	6
	Structure of the Nucleus	7
	Nomenclature.....	8
	Questions.....	10
	Suggested Reading	10
<i>Chapter 2</i>	Radioactive Decay	11
	Decay of Radionuclides.....	11
	Spontaneous Fission.....	11
	Alpha (α) Decay	11
	Beta (β^-) Decay.....	12
	Positron or β^+ Decay	14
	Electron Capture.....	14
	Isomeric Transition.....	15
	Radioactive Decay Equations.....	18
	General Equation	18
	Half-Life and Mean Life	19
	Units of Radioactivity	21
	Calculations	22
	Successive Decay Equations.....	23
	General Equation	23
	Transient Equilibrium	23
	Secular Equilibrium	25

	Statistics of Counting	27
	Error, Accuracy, and Precision.....	27
	Standard Deviation	27
	Standard Deviation of Count Rates	28
	Propagation of Errors.....	29
	Questions	30
	Suggested Reading	31
<i>Chapter 3</i>	Instruments for Radiation Detection and Measurement	33
	Gas-Filled Detectors	33
	Dose Calibrators.....	33
	Geiger-Müller Counters	35
	Scintillation Detecting Instruments.....	36
	Collimator	36
	Detector.....	37
	Photomultiplier Tube.....	37
	Preamplifier.....	38
	Linear Amplifier.....	38
	Pulse Height Analyzer	38
	Display or Storage.....	39
	Scintillation Camera	39
	Collimator	41
	Detector.....	41
	X, Y Positioning Circuit	42
	Pulse Height Analyzer	42
	Digital Image.....	43
	Display and Storage	43
	Tomographic Imagers.....	44
	Single Photon Emission Computed Tomography.....	45
	Positron Emission Tomography.....	45
	PET/CT and SPECT/CT	47
	Questions	48
	Suggested Reading	48
<i>Chapter 4</i>	Production of Radionuclides	49
	Cyclotron-Produced Radionuclides.....	49
	Gallium-67	52
	Iodine-123	52
	Indium-111	53
	Thallium-201	53
	Short-Lived Radionuclides	54
	Reactor-Produced Radionuclides	55
	Fission or (n, f) Reaction.....	56
	Iodine-131	57

	Molybdenum-99	57
	Neutron Capture or (n, γ) Reaction	57
	Target and Its Processing	58
	Equation for Production of Radionuclides	59
	Specific Activity	64
	Questions	65
	References and Suggested Reading	66
<i>Chapter 5</i>	Radionuclide Generators	67
	Principles of a Generator	67
	Important Radionuclide Generators	70
	^{99}Mo - $^{99\text{m}}\text{Tc}$ Generator	70
	^{68}Ge - ^{68}Ga Generator	79
	^{90}Sr - ^{90}Y Generator	79
	^{62}Zn - ^{62}Cu Generator	80
	^{82}Sr - ^{82}Rb Generator (Cardiogen-82)	80
	Questions	81
	References and Suggested Reading	81
<i>Chapter 6</i>	Radiopharmaceuticals and Methods of Radiolabeling	83
	Definition of a Radiopharmaceutical	83
	Ideal Radiopharmaceutical	84
	Easy Availability	84
	Short Effective Half-Life	84
	Particle Emission	85
	Decay by Electron Capture or Isomeric Transition	85
	High Target-to-Nontarget Activity Ratio	86
	Design of New Radiopharmaceuticals	87
	General Considerations	87
	Factors Influencing the Design of New Radiopharmaceuticals ..	88
	Methods of Radiolabeling	91
	Isotope Exchange Reactions	91
	Introduction of a Foreign Label	92
	Labeling with Bifunctional Chelating Agents	92
	Biosynthesis	92
	Recoil Labeling	93
	Excitation Labeling	93
	Important Factors in Labeling	93
	Efficiency of the Labeling Process	93
	Chemical Stability of the Product	94
	Denaturation or Alteration	94
	Isotope Effect	94
	Carrier-Free or No-Carrier-Added State	94
	Storage Conditions	94

Specific Activity.....	95
Radiolysis.....	95
Purification and Analysis.....	95
Shelf Life.....	96
Specific Methods of Labeling.....	96
Radioiodination.....	96
Labeling with ^{99m}Tc	101
Structure of ^{99m}Tc -Complexes.....	106
Oxidation States of ^{99m}Tc in ^{99m}Tc -Radiopharmaceuticals... ..	107
Kits for ^{99m}Tc -Labeling.....	109
Colloids and Labeled Particles.....	110
Additives and Preservatives.....	111
Questions.....	112
References and Suggested Reading.....	113
<i>Chapter 7</i> Characteristics of Specific Radiopharmaceuticals.....	115
^{99m}Tc -Labeled Radiopharmaceuticals.....	115
^{99m}Tc -Sodium Pertechnetate.....	115
^{99m}Tc -Macroaggregated Albumin.....	116
^{99m}Tc -Phosphonate and Phosphate Radiopharmaceuticals... ..	116
^{99m}Tc -Sulfur Colloid.....	118
^{99m}Tc -Albumin Colloid (Nanocolloid).....	119
^{99m}Tc -Pentetate (DTPA).....	119
^{99m}Tc -Labeled Red Blood Cells.....	120
^{99m}Tc -Iminodiacetic Acid Derivatives.....	121
^{99m}Tc -Hexamethylpropylene Amine Oxime (Ceretec).....	122
^{99m}Tc -Sestamibi (Cardiolite; Miraluma).....	123
^{99m}Tc -Tetrofosmin (Myoview).....	125
^{99m}Tc -Mercaptoacetylglycylglycylglycine (MAG3).....	125
^{99m}Tc -Ethyl Cysteinate Dimer (Neurolite).....	126
^{99m}Tc -Dimercaptosuccinic Acid (Succimer).....	126
^{99m}Tc -Gluceptate.....	127
^{99m}Tc -Technegas.....	127
Radioiodinated Radiopharmaceuticals.....	127
^{131}I -Sodium Iodide.....	127
^{123}I -Sodium Iodide.....	128
^{125}I -Albumin.....	129
^{123}I - or ^{131}I -Metaiodobenzylguanidine.....	129
^{125}I -Sodium Iothalamate.....	129
^{131}I -Tositumomab (Bexxar).....	130
Miscellaneous Radiopharmaceuticals of Clinical Interest.....	130
^{111}In -DTPA.....	130
^{133}Xe Gas.....	130

^{201}Tl -Thallos chloride	131
^{67}Ga -Citrate.....	131
^{32}P -Sodium Orthophosphate	131
^{89}Sr -Strontium Chloride (Metastron)	132
^{153}Sm -Ethylenediaminetetramethylene Phosphonic Acid (Quadramet).....	132
^{57}Co - or ^{58}Co -Cyanocobalamin	132
^{51}Cr -Labeled Red Blood Cells	132
Radiolabeled Leukocytes and Platelets	133
Radiolabeled Monoclonal Antibodies.....	136
Radiolabeled Peptides.....	144
Other Radiopharmaceuticals of Clinical Importance	145
PET Radiopharmaceuticals	145
^{18}F -Sodium Fluoride	145
^{18}F -Fluorodeoxyglucose.....	146
^{18}F -Fluorodopa	146
^{18}F -Fluorothymidine.....	147
^{15}O -Water	147
n- ^{15}O -Butanol	147
^{13}N -Ammonia	148
^{11}C -Sodium Acetate	148
^{11}C -Flumazenil	148
^{11}C -Methylspiperone	148
^{11}C -L-Methionine	149
^{11}C -Raclopride	149
^{82}Rb -Rubidium Chloride	149
Questions.....	150
References and Suggested Reading.....	151
<i>Chapter 8</i> Quality Control of Radiopharmaceuticals	153
Physicochemical Tests	153
Physical Characteristics	153
pH and Ionic Strength.....	154
Radionuclidic Purity.....	154
Radiochemical Purity	155
Chemical Purity	164
Radioassay.....	165
Biological Tests	168
Sterility	168
Apyrogenicity	170
Toxicity.....	172
Record Keeping.....	173
Questions.....	173
References and Suggested Reading.....	174

<i>Chapter 9</i>	Nuclear Pharmacy.....	175
	Concept.....	175
	Design of a Nuclear Pharmacy	175
	USP Chapter <797>: Pharmaceutical Compounding:	
	Sterile Preparations.....	179
	Operation of a Nuclear Pharmacy	180
	Receiving and Monitoring of Radioactive Packages	180
	Preparation of Radiopharmaceuticals	181
	Quality Control of Radiopharmaceuticals	185
	Storage.....	185
	Dispensing.....	185
	Radioactive Waste Disposal.....	188
	Infectious Waste Disposal.....	189
	Centralized Nuclear Pharmacy	189
	Questions.....	191
	References and Suggested Reading.....	191
<i>Chapter 10</i>	Internal Radiation Dosimetry.....	193
	Radiation Units.....	193
	Radiation Dosimetry	195
	Calculation of Radiation Absorbed Dose	196
	Radiation Dose in SI Units.....	199
	Effective Dose.....	199
	Questions.....	205
	References and Suggested Reading.....	205
<i>Chapter 11</i>	Radiation Regulations, Protection, and Uses.....	207
	Food and Drug Administration	207
	Investigational New Drug	208
	New Drug Application	208
	Exploratory IND.....	209
	Radioactive Drug Research Committee.....	211
	Difference Between RDRC and Exploratory IND.....	211
	PET Radiopharmaceuticals.....	212
	FDA Regulations for Compounding in Nuclear Pharmacies	213
	State Boards of Pharmacy.....	215
	Nuclear Regulatory Commission	216
	Agreement States.....	216
	Licenses	217
	Accreditation of Nuclear Medicine Facilities.....	218
	Radiation Protection.....	219
	Medical Uses of Radioactive Materials.....	230
	Department of Transportation	239

	European Regulations Governing Radiopharmaceuticals	242
	Drug Registration.....	243
	Good Manufacturing Practice.....	244
	European Pharmacopoeia	244
	Radiation Protection.....	245
	Questions.....	246
	References and Suggested Reading.....	247
<i>Chapter 12</i>	In Vitro and In Vivo Nonimaging Tests.....	249
	Radioimmunoassay	249
	Principle	249
	Methodology	250
	Sensitivity and Specificity.....	251
	Application	251
	Schilling Test	252
	Blood Volume.....	253
	¹²⁵ I-Serum Albumin Method.....	253
	⁵¹ Cr-Labeled Red Blood Cell Method	253
	Application	254
	Red Blood Cell Survival.....	254
	Questions.....	255
	Suggested Reading.....	255
<i>Chapter 13</i>	Diagnostic Uses of Radiopharmaceuticals in Nuclear	
	Medicine	257
	Central Nervous System	257
	Anatomy and Physiology.....	257
	Radiopharmaceuticals and Imaging Techniques.....	259
	^{99m} Tc-Ethyl Cysteinate Dimer (Neurolite)	259
	^{99m} Tc-Hexamethylpropylene Amine Oxime (Ceretek)	261
	Interventional Studies	262
	¹⁸ F-Fluorodeoxyglucose.....	263
	¹⁸ F-Fluorodopa	265
	Other Radiopharmaceuticals	265
	¹¹¹ In-DTPA.....	266
	Diagnosis	266
	Thyroid.....	267
	Anatomy and Physiology.....	267
	Radiopharmaceuticals and Imaging Techniques.....	268
	Diagnosis	271
	Lung.....	272
	Anatomy and Physiology.....	272
	Radiopharmaceuticals and Imaging Techniques.....	273
	^{99m} Tc-Labeled Macroaggregated Albumin	274

^{133}Xe Gas	276
$^{99\text{m}}\text{Tc}$ -Labeled Aerosol	276
$^{99\text{m}}\text{Tc}$ -Technegas	277
Diagnosis	279
Liver	279
Anatomy and Physiology	279
Radiopharmaceuticals and Imaging Techniques	280
Diagnosis	286
Spleen	286
Anatomy and Physiology	286
Radiopharmaceuticals and Imaging Techniques	286
Diagnosis	287
Kidney	288
Anatomy and Physiology	288
Radiopharmaceuticals and Imaging Techniques	289
Effective Renal Plasma Flow	292
Diagnosis	296
Skeleton	297
Anatomy and Physiology	297
Radiopharmaceuticals and Imaging Techniques	297
^{18}F -Sodium Fluoride	298
Diagnosis	299
Heart	299
Anatomy and Physiology	299
Radiopharmaceuticals and Imaging Techniques	303
^{201}Tl -Thallos Chloride	303
$^{99\text{m}}\text{Tc}$ -Sestamibi (Cardiolite)	306
^{82}Rb -Rubidium Chloride	310
^{13}N -Ammonia	310
Other Perfusion Radiopharmaceuticals	311
Metabolic Imaging	312
Other Metabolic Radiopharmaceuticals	313
Myocardial Infarct Imaging	314
Cardiac Innervation Imaging	315
Miscellaneous Imaging Procedures	319
Tumor Imaging	319
Thrombus Detection	328
Lymphoscintigraphy	329
Gastric Emptying Imaging	330
Meckel's Diverticulum Imaging	331
Gastrointestinal Bleeding Detection	331
Inflammatory Diseases and Infection Imaging	332
Parathyroid Imaging	334

Questions	335
References and Suggested Reading	337
<i>Chapter 14</i> Molecular Imaging.....	341
Methodology of Molecular Imaging.....	342
Conventional Molecular Imaging.....	342
Gene-Based Molecular Imaging	342
Oligodeoxynucleotide Antisense Probes to Image mRNA ..	346
Reporter Genes for Imaging.....	347
Gene Therapy	349
Gene Delivery	349
Specific Diseases	350
Nanoparticle Imaging	351
Questions.....	354
References and Suggested Reading.....	357
<i>Chapter 15</i> Therapeutic Uses of Radiopharmaceuticals	
in Nuclear Medicine	357
Treatment of Hyperthyroidism.....	357
Treatment of Thyroid Cancer.....	358
Whole-Body Imaging	359
Treatment with ^{131}I	359
Treatment of Bone Pain.....	361
^{32}P -Sodium Orthophosphate	361
^{89}Sr -Strontium Chloride (Metastron)	361
^{153}Sm -EDTMP (Quadramet)	362
Treatment of Liver Cancer.....	362
^{90}Y -TheraSpheres	362
^{90}Y -SIR-Spheres (SIR-TeX)	363
Treatment of Non-Hodgkin's Lymphoma.....	364
^{90}Y -Ibritumomab Tiuxetan (Zevalin)	364
^{131}I -Tositumomab (Bexxar).....	365
Polycythemia Vera and Leukemia.....	365
Pretargeted Radioimmunotherapy of Cancer.....	366
Questions.....	367
References and Suggested Reading.....	367
<i>Chapter 16</i> Adverse Reactions to and Altered Biodistribution	
of Radiopharmaceuticals.....	369
Adverse Reactions	369
Iatrogenic Alterations in the Biodistribution	
of Radiopharmaceuticals.....	370
Questions.....	372
References and Suggested Reading.....	372

Appendix A Abbreviation used in the text..... 373
Appendix B Terms used in the text..... 377
Appendix C Units and Constants 387
Appendix D Radioactive Decay of ^{99m}Tc 389
Appendix E Radioactive Decay of ¹³¹I..... 391
Appendix F Answers and Questions..... 393
Index..... 395