rex1	,

1	Basic Review1
	Matter, Elements, and Atoms1
	Simplified Structure of an Atom1
	Molecules
	Binding Energy, Ionization, and Excitation
	Forces or Fields
	Electromagnetic Forces
	Characteristic X-Rays and Auger Electrons5
	Interchangeability of Mass and Energy6
2	Nuclides and Radioactive Processes9
	Nuclides and Their Classification9
	Nuclear Structure and Excited States of a Nuclide9
	Radionuclides and Stability of Nuclides10
	Radioactive Series or Chain11
	Radioactive Processes and Conservation Laws11
	Alpha Decay11
	Beta Decay12
	Gamma Decay or Isomeric Transition14
	Decay Schemes
3	Radioactivity: Law of Decay, Half-Life, and Statistics21
	Radioactivity: Definition, Units, and Dosage21
	Law of Decay22
	Calculation of the Mass of a Radioactive Sample22
	Specific Activity23
	vii

viii Contents

	The Exponential Law of Decay	
	Half-Life	24
	Problems on Radioactive Decay	25
	Average Life (T _{av})	
	Biological Half-Life	26
	Effective Half-Life	26
	Statistics of Radioactive Decay	
	Poisson distribution, Standard Deviation, and Percent Standard Deviation	
	Propagation of Statistical Errors	28
	Room Background	29
4	Production of Radionuclides	31
	Methods of Radionuclide Production	31
	Reactor-Produced Radionuclides	31
	Accelerator- or Cyclotron-Produced Radionuclides	32
	Fission-Produced Radionuclides	33
	General Considerations in the Production of Radionuclides	33
	Production of Short-Lived Radionuclides, Using a Generator	34
	Principles of a Generator	34
	Description of a Typical Generator	36
5	Radiopharmaceuticals	41
	Design Considerations for a Radiopharmaceutical	41
	Selection of a Radionuclide	41
	Selection of a Chemical	
	Development of a Radiopharmaceutical	42
	Chemical Studies	42
	Animal Distribution and Toxicity Studies	43
	Human or Clinical Studies	43
	Quality Control of a Radiopharmaceutical	43
	Radionuclidic Purity	43
	Radiochemical Purity	43
	Chemical Purity	44
	Sterility	44
	Apyrogenicity	44
	Labeling of Radiopharmaceuticals with Technetium-99m	44
	Technetium-99m-Labeled Radiopharmaceuticals	45
	Tachnatium 90m Pertechnetate (99m TcO)	45

Technetium-99m-Labeled Sulfur Colloid	45
Technetium-99m-Labeled Macroaggregated Albumin (99mTc MAA)	46
Technetium-99m-Labeled Polyphosphate, Pyrophosphate, and Diphosphonate	46
Technetium-99m-Labeled Human Serum Albumin	46
Technetium-99m-Labeled Red Cells	46
Technetium-99m-Labeled 2,3-Dimercaptosuccinic Acid (DMSA)	46
Technetium-99m-Labeled Diethylenetriamine Pentaacetic Acid (DTPA)	46
Technetium-99m-Labeled Glucoheptonate	47
Technetium-99m-Labeled Mertiatide (MAG3)	47
Technetium-99m-Labeled 2,6-Dimethyl Acetanilide Iminodiacetic Acid (HIDA)	
and Related Compounds (Diethyl-IDA, PIPIDA, and DISIDA)	47
Technetium-99m-Labeled Sestamibi (Cardiolite)	47
Technetium-99m-Labeled Tetrofosmin (Myoview)	47
Technetium-99m-Labeled Brain Imaging Agents (Exametazime [Ceretec],	
Hexamethylpropyleneamine Oxime [HMPAO], and Ethyl Cysteinate Dimer [ECD])	47
Radioiodine-Labeled Radiopharmaceuticals (131I and 123I)	48
Iodine-131- or Iodine-123-Labeled Sodium Iodide	48
Other Iodine-123-Labeled Radiopharmaceuticals	48
Compounds Labeled with Other Radionuclides	48
Gallium-67 Citrate	48
Thallous-201 Chloride	49
Chromium-51-Labeled Red Cells	49
Indium-111-Labeled DTPA	49
Indium-111-Labeled Platelets and Leukocytes	49
Indium-111-Labeled DTPA Pentetreotide (OctreoScan)	49
Radiolabeled Monoclonal Antibodies and Synthetic Peptides	49
Radioactive Gases and Aerosols	50
Radiopharmeceuticals for PET Imaging	50
¹⁸ FDG (2-deoxy-fluoro-D-glucose)	51
Radiopharmaceuticals in Pregnant or Lactating Women	51
Therapeutic Uses of Radiopharmaceuticals	51
Design of a Radiopharmaceutical for Therapeutic Uses	52
Problems and Uses	52
Misadministration of Radiopharmaceuticals	52
Interaction of High-Energy Radiation With Matter	55
Interaction of Charged Particles (10 keV to 10 MeV)	55
Principal Mechanism of Interaction	55

6

	Differences between Lighter and Heavier Charged Particles	55
	Range R of a Charged Particle	56
	Factors That Affect Range, R	
	Bremsstrahlung Production	57
	Stopping Power (S)	57
	Linear Energy Transfer (LET)	57
	Difference between LET and Stopping Power S	58
	Annihilation of Positrons	58
	Interaction of x- or γ-rays (10 keV to 10 MeV)	58
	Attenuation and Transmission of X- or γ-Rays	58
	Attenuation through Heterogeneous Medium	60
	Mass Attenuation Coefficient, μ (mass)	60
	Atomic Attenuation Coefficient, μ (atom)	60
	Mechanisms of Interaction	60
	Dependence of μ (mass) and μ (linear) on Z	62
	Relative Importance of the Three Processes	63
	Interaction of Neutrons	64
7	Radiation Dosimetry	67
	General Comments on Radiation Dose Calculations	67
	Definitions and Units	67
	Radiation Dose, D	68
	Radiation Dose Rate, dD/dt	68
	Parameters or Data Needed	68
	Calculation of the Radiation Dose	69
	Step 1: Rate of Energy Emission	69
	Step 2: Rate of Energy Absorption	69
	General Comments on $\phi_i(T \leftarrow S)$	70
	Step 3: Dose Rate, dD/dt	
	Step 4: Average Dose, D	71
	Cumulated Radioactivity	71
	Simplification of Radiation Dose Calculations Using "S" Factor	
	Some Illustrative Examples	
	Radiation Doses in Routine Imaging Procedures	75
	Radiation Doses in Routine Imaging Procedures	

8	Detection of High-Energy Radiation	79
	What Do We Want to Know About Radiation?	79
	Simple Detection	79
	Quantity of Radiation	79
	Energy of the Radiation	79
	Nature of Radiation	79
	What Makes One Radiation Detector Better Than Another?	80
	Intrinsic Efficiency or Sensitivity	80
	Dead Time or Resolving Time	80
	Energy Discrimination Capability or Energy Resolution	81
	Other Considerations	81
	Types of Detectors	81
	Gas-Filled Detectors	82
	Scintillation Detectors (Counters)	86
	Semiconductor Detectors	94
9	In Vitro Radiation Detection	97
	Overall Efficiency E	97
	Intrinsic Efficiency	97
	Geometric Efficiency	97
	Well-type NaI(T1) Scintillation Detectors (Well Counters)	98
	Liquid Scintillation Detectors	100
	Basic Components	101
	Preparation of the Sample Detector Vial	102
	Problems Arising in Sample Preparation	102
10	In Vivo Radiation Detection: Basic Problems, Probes, and Rectilinear Scanners	105
	Basic Problems	105
	Collimation	105
	Scattering	106
	Attenuation	107
	Organ Uptake Probes	108
	NaI(Tl) Detector	108
	Collimator	108
	Miniature Surgical Probes	109
	Organ Imaging Devices	110
	Rectilinear Scanner	110

11	In Vivo Radiation Detection: Scintillation Camera	113
	Scintillation Camera	113
	Collimators	114
	Parallel Hole	114
	Detector, NaI(Tl) Crystal	116
	Position Determining Circuit (x, y Coordinates)	117
	Display	120
	Imaging with a Scintillation Camera	122
	Interfacing with a Computer or All-digital Camera	123
	Digitization in General	123
	Digitization in the Scintillation Camera	124
	Some Applications of Computers	124
	Automatic Acquisition of Images	124
	Display of Images	125
	Analysis of the Images	125
12	Operational Characteristics and Quality Control of a Scintillation Cam	nera131
	Quantitative Parameters for Measuring Spatial Resolution	131
	Point-Spread Function and FWHM	131
	Modulation Transfer Function	132
	Resolution of an Imaging Chain	132
	Quantitative Parameters for Measuring Sensitivity	133
	Point Sensitivity S _p	133
	Line Sensitivity S _L	133
	Plane Sensitivity S _A	133
	Factors Affecting Spatial Resolution and Sensitivity of an Imager	133
	Scintillation Camera	134
	Loss of Spatial Resolution Resulting from Septal Penetration	
	Variation in Spatial Resolution with Depth	135
	Uniformity and High Count Rate Performance of a Scintillation Camera	135
	Uniformity	135
	High Count Rate Performance	137
	Quality Control of Imaging Devices	137
	Scintillation Camera	138
13	Detectability or Final Contrast in an Image	141
	Parameters that Affect Detectability of a Lesion	
	Object Contrast	141

		Contents	xiii
	Spatial Resolution and Sensitivity of an Imaging Device		142
	Statistical (Quantum) Noise		142
	Projection of Volume Distribution into Areal Distribution		144
	Compton Scattering of γ-Rays		144
	Attenuation		145
	Object Motion	••••••	145
	Display Parameters	••••••	145
	Contrast-Detail Curve		145
	Receiver Operator Characteristic (ROC) Curve		146
.4	Emission Computed Tomography		.149
	Principles of Transverse Tomography		149
	Considerations in Data Acquisition		150
	Reconstruction of the Cross Section	•••••	151
	Attenuation Correction in Filtered Back Projection		153
	Scatter Correction in Filtered Back Projection		153
	Single-photon Emission Computed Tomography		154
	Data Acquisition with a Scintillation Camera		154
	Collimators		155
	Other Requirements or Sources of Error		155
	Dedicated SPECT Systems		156
	Positron Emission Tomography		157
	Why PET?		157
	Principles of PET		158
	PET Instrumentation	•••••	160
	PET-CT and PET-SPECT		161
.5	Biological Effects of Radiation and Risk Evaluation from Radiation	Exposure	.165
	Mechanism of Biological Damage		165
	Factors Affecting Biological Damage		166
	Radiation Dose		166
	Dose Rate		166
	LET or Type of Radiation		166

 Type of Tissue
 166

 Amount of Tissue
 167

 Rate of Cell Turnover
 167

 Biological Variation
 167

 Chemical Modifiers
 167

 Deleterious Effects in Humans
 167

Late Effects
Different Radiation Exposures and the Concepts of Equivalent Dose (Dose Equivalent) and Effective Dose (Effective Dose Equivalent)
and Effective Dose (Effective Dose Equivalent) 10 Sources of Radiation Exposure 11 Effective Doses in Nuclear Medicine and Comparison with Other Sources of Exposure 11 Methods of Safe Handling of Radionuclides and Pertaining Rules and Regulations 12 Principles of Reducing Exposure from External Sources 11 Time 12 Distance 12 Shielding 12 Avoiding Internal Contamination 12 The Radioactive Patient 13 Rules and Regulations 14
Sources of Radiation Exposure
Effective Doses in Nuclear Medicine and Comparison with Other Sources of Exposure
16 Methods of Safe Handling of Radionuclides and Pertaining Rules and Regulations
and Regulations
Principles of Reducing Exposure from External Sources
Time 1 Distance 1 Shielding 1 Avoiding Internal Contamination 1 The Radioactive Patient 1 Rules and Regulations 1
Distance
Shielding
Avoiding Internal Contamination
The Radioactive Patient1 Rules and Regulations1
Rules and Regulations1
U.S. Regulatory Agencies1
Exposure or Dose Limits: Annual Limit on Intake and Derived Air Concentration1
ALARA Principle1
Types of Licenses
Radiation Safety Committee and Radiation Safety Officer
Personnel Monitoring1
Receipt, Use, and Disposal of Radionuclides
Control and Labeling of Areas Where Radionuclides are Stored and/or Used1
Contamination Survey and Radiation-Level Monitoring1
Receiving and Shipping (Transport) of Radioactive Packages
Accidental Radioactive Spills1
A Appendix A: Physical Characteristics of Some Radionuclides of Interest in Nuclear
Medicine18
B Appendix B: CGS and SI Units18
C Appendix C: Exponential Table18
D Appendix D: Radionuclides of Interest in Nuclear Medicine19
E Appendix E: Organ Masses of a Standard Man19
Answers
Suggestions for Further Reading