Radiation Detection and Measurement

Third Edition

Glenn F. Knoll

Professor of Nuclear Engineering and Radiological Sciences University of Michigan Ann Arbor, Michigan



Contents

Chapter 1	Radiation Sources	1
I.	Units and Definitions	
II.	Fast Electron Sources	3
III.	Heavy Charged Particle Sources	(
IV.	Sources of Electromagnetic Radiation	1:
V.	Neutron Sources	19
Chapter 2	Radiation Interactions	29
I.	Interaction of Heavy Charged Particles	30
II.	Interaction of Fast Electrons	43
III.	Interaction of Gamma Rays	48
IV.	Interaction of Neutrons	55
V.	Radiation Exposure and Dose	57
Chapter 3	Counting Statistics and Error Prediction	65
I.	Characterization of Data	66
II.	Statistical Models	70
III.	Application of Statistical Models	79
IV.	Error Propagation	86
V.	Optimization of Counting Experiments	92
VI.	Limits of Detectability	94
VII.	Distribution of Time Intervals	97
Chapter 4	General Properties of Radiation Detectors	103
I.	Simplified Detector Model	103
II.	Modes of Detector Operation	104
III.	Pulse Height Spectra	110
IV.	Counting Curves and Plateaus	111
V.	Energy Resolution	113
VI.	Detection Efficiency	116
VII.	Dead Time	119
Chapter 5	Ionization Chambers	129
I.	The Ionization Process in Gases	129
II.	Charge Migration and Collection	133
III.	Design and Operation of DC Ion Chambers	136
IV.	Radiation Dose Measurement with Ion Chambers	140
V.	Applications of DC Ion Chambers	145
VI.	Pulse Mode Operation	148

Chapter 6	Proportional Counters	159
I.	Gas Multiplication	159
II.	Design Features of Proportional Counters	164
III.	Proportional Counter Performance	169
IV.	Detection Efficiency and Counting Curves	184
V.	Variants of the Proportional Counter Design	188
Chapter 7	Geiger-Mueller Counters	201
I.	The Geiger Discharge	202
II.	Fill Gases	204
III.	Quenching	204
IV.	Time Behavior	206
V.	The Geiger Counting Plateau	208
VI.	Design Features	210
VII.	Counting Efficiency	212
VIII.	Time-to-First-Count Method	214
IX.	G-M Survey Meters	215
Chapter 8	Scintillation Detector Principles	219
I.	Organic Scintillators	220
II.	Inorganic Scintillators	231
III.	Light Collection and Scintillator Mounting	247
Chapter 9	Photomultiplier Tubes and Photodiodes	265
I.	Introduction	265
II.	The Photocathode	266
III.	Electron Multiplication	270
IV.	Photomultiplier Tube Characteristics	274
V.	Ancillary Equipment Required with Photomultiplier Tubes	283
VI.	Photodiodes as Substitutes for Photomultiplier Tubes	287
VII.	Scintillation Pulse Shape Analysis	292
VIII.	Hybrid Photomultiplier Tubes	297
IX.	Position-Sensing Photomultiplier Tubes	300
X.	Photoionization Detectors	302
Chapter 10	Radiation Spectroscopy with Scintillators	30
I.	General Consideration in Gamma-Ray Spectroscopy	307
II.	Gamma-ray Interactions	308
III.	Predicted Response Functions	312
IV.	Properties of Scintillation Gamma-Ray Spectrometers	320
V.	Response of Scintillation Detectors to Neutrons	342
VI.	Electron Spectroscopy with Scintillators	343
VII.	Specialized Detector Configurations Based on Scintillation	344
Chapter 11	Semiconductor Diode Detectors	353
I.	Semiconductor Properties	354
II.	The Action of Ionizing Radiation in Semiconductors	365
III.	Semiconductors as Radiation Detectors	36
IV.	Semiconductor Detector Configurations	37
V.	Operational Characteristics	382

		Table of Contents	xiii
VI.	Applications of Silicon Diode Detectors		391
Chapter 12	Germanium Gamma-Ray Detectors		405
I.	General Considerations		405
II.	Configurations of Germanium Detectors		406
III.	Germanium Detector Operational Characteristics		413
IV.	Gamma-Ray Spectroscopy with Germanium Detectors		426
Chapter 13	Other Solid-State Detectors		457
I.	Lithium-Drifted Silicon Detectors		457
II.	Semiconductor Materials Other than Silicon or Germanium		477
III.	Avalanche Detectors		489
IV.	Photoconductive Detectors		491
V.	Position-Sensitive Semiconductor Detectors		492
Chapter 14	Slow Neutron Detection Methods		505
I.	Nuclear Reactions of Interest in Neutron Detection		505
II.	Detectors Based on the Boron Reaction		509
III.	Detectors Based on Other Conversion Reactions		517
IV.	Reactor Instrumentation		522
Chapter 15	Fast Neutron Detection and Spectroscopy		537
I.	Counters Based on Neutron Moderation		538
II.	Detectors Based on Fast Neutron-Induced Reactions		545
III.	Detectors that Utilize Fast Neutron Scattering		553
Chapter 16	Pulse Processing and Shaping		577
I.	Device Impedances		577
II.	Coaxial Cables		578
III.	Pulse Shaping		585
Chapter 17	Linear and Logic Pulse Functions		605
I.	Linear and Logic Pulses		605
II.	Instrument Standards		606
III.	Application Specific Integrated Circuits (ASICs)		607
IV.	Summary of Pulse-Processing Units		608
V.	Components Common to Many Applications		610
VI.	Pulse Counting Systems		619
VII.	Pulse Height Analysis Systems		626
VIII.	Digital Pulse Processing		647
IX.	Systems Involving Pulse Timing		659
X.	Pulse Shape Discrimination		679
Chapter 18	Multichannel Pulse Analysis		685
I.	Single-Channel Methods		685
II.	General Multichannel Characteristics		687
III.	The Multichannel Analyzer		691
IV.	Spectrum Stabilization and Relocation		700
V.	Spectrum Analysis		704

xiv Table of Contents

Chapter 19	Miscellaneous Detector Types	711
I.	Cherenkov Detectors	711
II.	Gas-Filled Detectors in Self-Quenched Streamer Mode	714
III.	High-Pressure Xenon Spectrometers	716
IV.	Liquid Ionization and Proportional Counters	717
V.	Cryogenic and Superconducting Detectors	719
VI.	Photographic Emulsions	727
VII.	Thermoluminescent Dosimeters and Image Plates	731
VIII.	Track-Etch Detectors	736
IX.	Superheated Drop or "Bubble Detectors"	741
X.	Neutron Detection by Activation	744
XI.	Detection Methods Based on Integrated Circuit Components	751
Chapter 20	Background and Detector Shielding	757
ı.	Sources of Background	757
II.	Background in Gamma-Ray Spectra	762
III.	Background in Other Detectors	766
IV.	Shielding Materials	767
V.	Active Methods of Background Reduction	771
Appendix A	The NIM and CAMAC Instrumentation Standards	777
Appendix B	Derivation of the Expression for Sample Variance in Chapter 3	783
Appendix C	Statistical Behavior of Counting Data for Variable Mean Value	785
Appendix D	The Shockley-Ramo Theorem for Induced Charge	789
List of Tables		795
Index		796