

# Index

Note: Page numbers followed by f indicate figures; those followed by t indicate tables.

## A

A (mass number), 13  
 Absolute activity, assay of, 177  
 Absolute quantification of PET, 339-340  
 Absolute spatial linearity, of gamma cameras, 229-230  
 Absorbed dose, 407, 432-435, 433t. *See also* Radiation dose.  
   air kerma and, 428-430, 434  
   average, 408, 414, 417, 428, 429t  
   radiation safety and, 427, 428, 429-430, 435  
   scaling factor for, 430, 430f  
   units for, 431-432  
 Absorbed dose constant, equilibrium, 412-413  
 Absorbed fraction, 413-414, 414f, 415t  
   specific absorbed fraction, 414-415  
 Absorbed fraction (MIRD) method, 407. *See also* Radiation dosimetry, internal.  
   absorbed fraction and, 413-414  
   anatomic models for, 409, 414, 414f, 415t, 424  
   cumulated activity and, 409-410, 424  
   dose reciprocity theorem and, 415  
   effective dose and, 417  
   equilibrium absorbed dose constant and, 412-413  
   limitations of, 424-425  
   mean dose per cumulated activity and, 415-416  
   specific absorbed fraction and, 414-415  
   steps in, 408-409  
   surface dose and, 409  
   time-activity curves and, 409-410, 410f-411f  
   tissue weighting factors for, 417, 425t  
   whole-body dose and, 417, 425t  
 Absorbers. *See also* Attenuation.  
   atomic number of, 75, 79, 81f  
   buildup factors for, 83, 84t  
   charged particle interactions in. *See* Charged particles.  
   density of, 71, 72, 73, 73f, 75, 78-79

Absorbers (*Continued*)  
   photon attenuation in, 78-85  
     broad-beam, 79-80, 81f, 83, 84t  
     coefficients for, 78-79  
     narrow-beam, 79-83, 81f, 82t  
     with polyenergetic sources, 84-85  
   radiation dose in, 407  
   thickness of. *See also* Range of charged particles.  
   attenuation and, 78-85.  
     *See also* Attenuation.  
   detection efficiency and, 160-162, 166f  
   half-value, 82, 82t  
   range and, 70-74. *See also* Range of charged particles.  
   tenth-value, 82, 82t  
   transmission factors for, 83  
 Absorption, detection efficiency and, 166, 173-175, 174f  
 Absorption edges, 79, 80f  
 Absorptive collimation, 201, 220, 312-321, 322  
   electronic collimation vs., 308  
 Accelerators, charged-particle, 47-50, 48f-50f, 50t  
 Accidental coincidences. *See* Random coincidences.  
 ACD. *See* Annihilation coincidence detection (ACD).  
 ACF. *See* Attenuation correction factor (ACF).  
 Acquisition modes, 322, 329, 332-333, 334, 369  
 Activation cross section, 53-54, 54f  
 Activation rates, 54-56  
 Activation thresholds, 50t, 54  
 Active transport, 389  
 Activity, 31-32  
   absolute, assay of, 177  
   cumulated. *See* Cumulated activity.  
   decay constant and, 31  
   definition of, 31-32  
   equivalent, 177  
   measurement of  
     with dose calibrator, 89, 89f, 189-190  
     with NaI(Tl) well counter, 177  
   of mixed samples, 38-39, 39f

Activity (*Continued*)  
   of mixture  
     parent-daughter, 39-42, 39f, 40f, 41f, 42f  
     of unrelated species, 38-39, 39f  
   product, buildup and decay of, 56  
   specific, 37-38  
     carrier-free, 37-38  
     in nuclear medicine, 38, 56  
     product, 56  
     of radionuclides, 57-58  
     of radiopharmaceuticals, 59  
     saturation level of, 56  
   typical amounts of, 32  
   units of, 31-32  
     for cumulated activity, 409  
   in voxel, 285, 339-340, 364, 367  
 ADCs. *See* Analog-to-digital converters (ADCs).  
 AES. *See* Automatic external standardization (AES) method.  
 Agreement states, 431  
 Air kerma, 89, 428-431, 429t  
 Airborne radioactive materials, 432, 432t, 438  
 ALARA concept, 433-434, 437-438, 439  
 Albumin, radiolabeled, 393, 394  
 Aliasing, 263, 273, 484-485, 485f, 487  
 $\alpha$  ( $e/\gamma$  conversion ratio), 24  
 Alpha ( $\alpha$ ) particles. *See also* Charged particles.  
   acceleration of, in cyclotron, 47  
   Cerenkov effect and, 68-70  
   decay of, 26-28  
   detection of, with survey meter, 440  
   emission of, 12, 15, 26, 27, 28  
   energy losses by, 63-65. *See also* Energy losses.  
   equivalent dose of, 408t  
   interactions with matter, 63-70  
     Cerenkov effect in, 68-70  
     energy losses in, 66, 70  
     ranges in, 70-71, 82-83, 83t  
     specific ionization in, 68, 69f, 71  
     tracks in, 66, 67, 67f, 68, 70  
   range of, 65, 70, 70f, 72f-73f, 82t

- Alpha ( $\alpha$ ) particles (*Continued*)  
 shielding of, 71  
 tracks of, 66-67, 67f  
 energy deposition along, 67-68  
 length of, 70, 70f, 72f-73f
- Alumina, in  $^{99m}\text{Mo}$ - $^{99m}\text{Tc}$  generators, 51, 51f, 53
- Aluminum ion in  $^{99m}\text{Tc}$ , 53
- Alzheimer's disease, FDG-PET in, 341-342, 342f
- Amplification factor, gas  
 in Geiger-Müller counters, 92-93, 94f  
 in proportional counter, 91, 92f
- Amplifiers, 110-113, 110f, 111f, 114f  
 baseline shift in, 112-113, 112f  
 bipolar output of, 113  
 dead time and, 168  
 in nuclear instrument module, 122-123  
 pulse pileup in, 112-113, 112f  
 pulse shaping by, 110-113, 110f  
 in rate meter, 120-121  
 resistor-capacitor, 110f, 111-112, 112f
- Analog buffers, 213-214
- Analog radiopharmaceuticals, 60, 61, 382
- Analog rate meters, 120-121, 120f
- Analog signals, digitization of, 363, 364, 365f
- Analog tracers, 382
- Analog-to-digital converters (ADCs), 116-118, 116f, 120, 124, 363  
 of gamma camera, 196-197, 196f, 198, 365f
- Anatomic models for radiation dosimetry, 409, 414, 414f, 415t, 424. *See also* Phantoms.
- Anger, Hal, 2, 4f, 95-196
- Anger cameras. *See* Gamma cameras.
- Angular sampling intervals, 263-265, 266, 266f, 301
- Angular sampling range, 266, 266f  
 in SPECT, 281, 301
- Annihilation coincidence detection (ACD), 307-308. *See also* Positron emission tomography (PET).  
 basic principles of, 307-308, 308f, 309f  
 coincidence unit in, 121-122, 121f  
 counting rates in, 321  
 effective positron range and, 313, 313f  
 electronic collimation and, 308  
 energy resolution in, 150  
 event types in  
 prompt coincidences, 322-324, 322f, 340  
 random coincidences, 322-332, 322f  
 corrections for, 336-337  
 estimation of, 336, 340
- Annihilation coincidence detection (ACD) (*Continued*)  
 scatter coincidences, 322f, 323-324, 329-330  
 true coincidences, 322-324, 322f  
 geometric efficiency for, 319-322  
 noncolinearity in, 314, 315f, 316  
 root mean square effective range and, 314  
 scintillators for, 309-310  
 sensitivity in, 308, 312, 319-320, 321, 322  
 spatial resolution in  
 depth-of-interaction effect in, 316-318, 317f  
 detectors and, 310, 311f, 312  
 with gamma cameras, 209-211, 210f, 211f  
 geometric efficiency and, 319-321  
 with PET scanner, 323  
 positron physics and, 312-316, 313f-315f, 313t  
 reconstruction filters and, 319  
 sampling and, 318-319, 318f  
 system resolution in, 314-315  
 in time-of-flight PET, 309-310, 310f  
 time-to-amplitude converter in, 118, 118f
- Annihilation photons, 25, 25f  
 after pair production, 77, 77f  
 in annihilation coincidence detection, 307-308, 308f-309f  
 interactions with matter, 74-78  
 in radiation detectors, 142, 144, 145-146, 145f, 149, 150, 151, 159  
 shielding for, 437
- Annihilation reaction, 25, 25f
- Anode  
 in cathode ray tubes, 123, 123f  
 in ionization detectors, 87, 88f  
 in photomultiplier tubes, 98-99, 98f
- Anthracene, 188
- Anticoincidence circuits, 113, 114f
- Antineutrino, 20
- Application-specific integrated circuits (ASICs), 363
- Archival systems for digital images, 378
- Arithmetic mean in conjugate counting, 287-293, 289f
- Artifacts  
 aliasing, 263  
 barrel, 216-217, 216f  
 from breath-holding, 359  
 from contrast agents, artifacts from, 359-360  
 in CT-based attenuation correction, 358-360, 359f  
 from dental implants, 360
- Artifacts (*Continued*)  
 motion, 234, 266, 359  
 attenuation correction artifacts and, 359  
 breath-holding and, 359  
 image quality and, 234, 266, 359  
 pincushion, 199-200, 215f-216f, 216-217  
 in SPECT, 302  
 structured noise from, 243  
 truncation, 359, 359f
- Atomic emissions, 10-13, 11f-12f  
 from radionuclides, 57, 58t
- Atomic mass, isotope effect and, 20
- Atomic mass unit, 7
- Atomic number (Z), 9, 13-14  
 binding energy and, 10  
 collisional losses and, 64-65  
 definition of, 9, 13  
 effective, 65, 101t, 103-104  
 fluorescent yield and, 12, 13f  
 of naturally occurring elements, 445-447  
 photon attenuation and, 78-79, 81f  
 radiation losses and, 64-65  
 of scintillators, 101t, 102, 103-104
- Atomic physics, basic concepts of, 7-18
- Atomic weight, 13
- Atoms, 9-13, 10f, 11f  
 binding energy of, 15  
 Bohr, 9, 10f  
 characteristic x rays of.  
*See* Characteristic x rays.  
 composition and structure of, 9  
 notation for, 12-15  
 nuclear, 9  
 nucleus of. *See* Nucleus.
- Attenuation, 78-85, 160-162.  
*See also* Absorbers.  
 broad-beam, 79-80, 81f, 83, 84t  
 coefficients for, 78-79  
 conjugate counting and, 287-291, 287f, 288f, 289f, 290f, 291t, 292f, 292t, 293  
 contrast-media-related, 359-360  
 correction factors for, 293-294, 294f  
 detection efficiency and, 160-164  
 narrow-beam, 79-83, 81f, 82t  
 in PET, correction of, 338-339, 338f  
 in PET/CT and SPECT/CT, correction of, 356-360  
 artifacts in, 358-360, 359f  
 image segmentation in, 357  
 mapping in, 357-358, 358f  
 of photons, 78-85, 78f, 80f  
 broad-beam, 79-80, 81f, 83, 84t  
 coefficients for, 78-79  
 narrow-beam, 79-83, 81f, 82t  
 with polyenergetic sources, 84-85  
 quality assurance and, 302  
 scattering and, 286, 294f, 302  
 in SPECT, 287-293, 291t-292t

- Attenuation (*Continued*)  
 conjugate counting and, 287  
 correction of, 293-294  
   Chang multiplicative  
     method for, 294, 294f,  
     296, 297f  
   scatter correction and,  
     296-299, 298f  
   transmission scans and,  
     294-296, 295f-297f  
 transmission scans and, 294-295,  
 295f, 296f, 297f  
 in vivo probe measurements and,  
 192
- Attenuation coefficients, 78-79, 78f,  
 80f, 81f. *See also* Linear  
 attenuation coefficients; Mass  
 attenuation coefficients.  
 scatter corrections and, in  
 SPECT, 297, 297f
- Attenuation correction factor  
 (ACF)  
 for PET, 338  
 for SPECT, 293
- Attenuation maps  
 in SPECT, 294-296, 296f,  
 298-299  
 in SPECT/CT and PET/CT,  
 357-358
- Audio systems, frequency response  
 curves for, 236-237, 236f
- Auger effect, 10-13, 12f
- Auger electrons, 10-13, 12f  
 after electron capture, 24  
 after internal conversion, 23  
 after ionization, 63  
 after photoelectron ejection, 74,  
 78t  
 photoelectric effect and, 74
- Automatic external  
 standardization (AES)  
 method, 186-187, 187f
- Autoradiography, deoxyglucose  
 method and, 401
- Avalanche ionization  
 in Geiger-Müller counters, 92-93,  
 94f  
 in ionization chambers, 91, 92f  
 in proportional counters, 91, 92f
- Avalanche photodiode detectors,  
 99-100, 332
- Average absorbed dose, 408, 414,  
 417, 424, 428, 429t
- Average lifetime, 34, 82  
 cumulated activity and, 410,  
 411f
- Average range for electrons, 73
- Averaging, effects of, 130
- Axial deviation of detector heads,  
 303
- Axial resolution, 301
- B**
- Background counting rates, 131  
 contrast and, 239-240  
 daily measurement of, 172  
 detectability and, 240  
 image noise and, 240  
 of liquid scintillation counter,  
 184
- Background counting rates  
 (*Continued*)  
 of NaI(Tl) conventional detector,  
 190  
 of NaI(Tl) well counter, 173, 174,  
 177-178, 180, 181  
 pulse-height analysis and, 132,  
 184-185  
 random coincidences causing,  
 336  
 scattered radiation and, 240-241,  
 241f  
 of semiconductor detector, 190  
 sources of, 240-242  
 statistics of, 131, 132-133
- Background information density,  
 244
- Background radiation  
 effective dose from, 427  
 sources of, 177-178, 427
- Background subtraction, 242-243
- Backprojection. *See also*  
 Reconstruction tomography.  
 definition of, 257  
 filtered. *See* Filtered  
   backprojection (FBP).  
 simple, 256-258, 266f  
 in SPECT, 294, 296
- Backscatter peak, 143f, 144, 151
- Backscattered photons, 75,  
 166-167, 167f
- Backscattering, 75  
 detection efficiency and, 163, 167,  
 167f
- Badge dosimeters, 440-441, 440f
- BaF<sub>2</sub>, 102-103, 310, 322t
- Bar phantoms, 235, 235f  
 modular transfer functions and,  
 237-238
- Barn, 53-54
- Barrel distortion, 216-217, 216f
- Baseline restoration, 112-113
- Baseline shift, 112-113, 112f  
 dead time losses and, 168  
 in gamma camera, 220  
 in pulse-height spectrometry,  
 146, 147
- Bateman equations, 39-40, 39f
- Beam hardening, 84
- Becquerel (Bq), 31
- Becquerel, Henry, 2, 9
- Becquerels per gram, 37
- $\beta^+$  decay, 25-26, 26f
- $\beta^-$  decay, 20-21  
 inverse, 24-25
- ( $\beta^+$ , EC) decay, competitive, 26
- $\beta^+$  emission. *See* Positron ( $\beta^+$ ,  
 $\gamma$ ) emission; Positron ( $\beta^+$ )  
 emission; Positrons.
- $\beta^-$  emission, 20-21, 20f, 21f  
 in decay series, 21-22, 22f  
 by fission products, 44, 45  
 by neutron-activated  
 radionuclides, 46
- $\beta^-$  emitters  
 in cancer therapy, 61  
 detection and measurement of, 21  
 with gas flow counter, 183  
 with LS system, 183, 183t  
 problems in, 166-167, 167f  
 shielding of, 65, 66f
- ( $\beta^+$ ,  $\gamma$ ) decay, 25-26
- ( $\beta^+$ ,  $\gamma$ ) decay, 21-22, 22f
- ( $\beta^+$ ,  $\gamma$ ) emission, 21-22, 22f  
 in medical applications, 46t, 57  
 metastable nuclide vs., 24
- Beta ( $\beta$ ) particles, 20-21. *See also*  
 Charged particles; Electrons.  
 backscattering of, 166-167,  
 167f  
 Cerenkov effect and, 68-70  
 detection and measurement of,  
 21  
 with Bremsstrahlung counting,  
 168  
 with Geiger-Müller counters,  
 166-167, 167f  
 problems in, 166-168  
 with proportional counters,  
 166-167, 167f  
 with survey meters, 166-167,  
 166f  
 energy losses by, 63-65. *See also*  
 Energy losses.  
 energy spectrum for, 21, 21f  
 interactions with matter, 63-70  
 Cerenkov effect and, 68-70  
 radiation losses in, 64-65, 67f  
 range of, 71-72, 72f, 73t  
 self-absorption of, 166-167,  
 167f  
 tracks of, 66-67, 67f  
   energy deposition along,  
     67-68  
   length of, 71, 73t
- Beta-particle emitters, ranges for,  
 73, 73t
- Beta-particle probes, miniature,  
 194
- BGO. *See* Bismuth germanate  
 (BGO).
- Binary numbers, 364-365
- Binding affinity, 403
- Binding energy  
 of atoms, 15  
 of electrons, 9-10, 11f  
   photoelectric effect and, 74  
 nuclear, 15-16  
   nuclide stability and, 17-18,  
   17f
- Binding potential, 402-403
- Biologic excretion curve, 410-412
- Biologic half-life, 59
- Bipolar pulse, 112, 115
- Bis-MSB [*p*-bis-(omethylstyryl)  
 benzene], 105, 187
- Bismuth germanate (BGO), 101t,  
 102-103  
 detection efficiency of, 161, 161f,  
 162  
 mass attenuation coefficients of,  
 477-478  
 in PET systems, 316, 324, 324f,  
 325, 325f, 328, 328f, 334  
 energy resolution and, 337  
 sensitivity and, 321, 322t
- Bits, 364-365
- Bladder, surface dose to, 409
- Blank scans, 338
- Block detectors, 324-325, 325f,  
 327f  
 modified, 325-326, 326f-327f

- Blood flow  
 measurement of  
   area-height method for, 396, 396f  
   central volume principle and, 380, 394  
   clearance methods for, 394-396, 396f  
   diffusible tracers for, 394-395  
   equilibrium methods for, 393  
   Kety-Schmidt method for, 395  
   labeled microsphere technique for, 393-394  
   modeling for, 383, 386-388, 388f  
   nondiffusible tracers for, 394  
   reference sample technique for, 393-394  
   tracers for, 380, 381, 381t, 383-384, 386, 387-388, 390f, 393-396  
     labeled ammonia as, 341-342, 479  
     trapping methods for, 393-394  
   tracer delivery and, 387
- Blood samples, counting systems for, 105, 173, 182
- Blood volume, tracers for, 381t, 383
- Blumgart, H.L., 2
- Blunders, 125
- Blurring. *See also* Artifacts;  
 Image quality; Spatial resolution.  
 convolution and, 489, 491, 492  
 motion, 234, 266  
   attenuation correction artifacts and, 359  
   breath-holding and, 359  
   image quality and, 234, 266, 359  
 nonlinearity, 314, 315f, 316  
 1/r blurring, 258, 260-261  
 spectral, 144, 148-151. *See also* Energy resolution.
- Blurring tomography, 257
- Bohr atom, 9, 10f
- Bone  
 attenuation by, 287, 294, 338  
 energy absorption in, 430  
 f factor for, 430, 430f  
 positron ranges in, 314
- Bone marrow. *See also* Organs.  
 absorbed fraction in, 413
- Bone scan, 1, 5t, 60t, 197, 207f
- Bq (becquerel), 31
- Bragg ionization peak, 68, 69f
- Brain  
 blood flow in  
   imaging of, 323, 330, 330f, 375-376, 377f, 394, 395  
   during visual stimulation, 371-372, 372f  
   tracer measurements of, 394-395  
   receptor studies of, 304-305, 380, 381t, 402, 403
- Brain imaging  
 co-registration of images in, 375-376, 377f
- Brain imaging (*Continued*)  
 with gamma camera, 4f  
 parametric, for glucose metabolism, 400, 401f  
 with PET, 330-331, 330f  
   3-D acquisition in, 332, 333f, 334  
   FDG for, 342, 342f, 397-398, 398f, 400, 401f  
   perfusion studies in, 388, 394  
   random coincidences in, 323  
   resolution of, 330-331, 330f  
   scatter in, 323, 332, 338  
   systems for, 330, 330f  
   time-activity curves and, 373, 374f  
   during visual stimulation, 371, 372f  
   region of interest in, 372, 372f  
   with SPECT, 280-281, 282f, 304-305, 304f  
     attenuation corrections in, 294  
     in cerebral perfusion studies, 304-305, 304f  
     perfusion studies in, 304-305, 304f  
     systems for, 301, 302-303
- Brain phantom  
 image contrast in, 240, 241f  
 motion blurring in, 234, 234f
- Branching decay, 27-28, 31
- Branching ratio, 31, 40
- Breast imaging  
 gamma camera for, 207, 208f  
 PET systems for, 330-331, 331f  
 sentinel-node, gamma-ray probes for, 192-193
- Bremsstrahlung, 64, 64f-66f  
 charged-particle tracks and, 66, 67f, 68  
 electron transmission curve and, 71  
 interactions with matter, 74-78  
 penetrating ability of, 195  
 radiation losses and, 64, 65, 65f, 66f  
 shielding and, 65, 67f, 437  
 in x-ray tubes, 346
- Bremsstrahlung counting, of  $\beta$  particles, 168
- Broad-beam attenuation coefficient, 297, 297f
- Broad-beam geometry, 79-80, 81f, 83, 84t
- Broad-scope licenses, 435
- Buildup factors, 83, 84t
- Bulk flow across capillaries, 389
- Byte, 365
- C**
- Cadmium telluride (CdTe)  
 detectors, 89t, 96-97, 158, 164.  
*See also* Radiation detectors;  
 Semiconductor detectors.  
 detection efficiency of, 164  
 energy resolution of, 190, 191  
 for gamma-ray probes, 193
- Cadmium telluride (CdTe) detectors (*Continued*)  
 for intraoperative probe, 193, 193f  
 intrinsic efficiency of, 158
- Cadmium zinc telluride (CZT)  
 detectors, 89t, 96-97, 151-152, 153f. *See also* Radiation detectors;  
 Semiconductor detectors.  
 for cardiac SPECT, 281, 283f  
 detection efficiency of, 164  
 energy resolution of, 190, 191  
 for gamma-ray probes, 293  
 for intraoperative probe, 193-194, 193f  
 intrinsic efficiency of, 158  
 mass attenuation coefficients of, 477-478
- Calibration  
 of liquid scintillation counter, 185  
 of NaI(Tl) detector, 147-148, 148f  
 of NaI(Tl) well counter, 178  
 precalibrated radionuclides and, 35  
 quality assurance procedures for, 172
- Calibration factor, 339-340
- Calibration sources, 164, 165f, 165t, 166  
 absolute activity assays and, 177  
 americium-241 as, 28  
 detection efficiency and, 164-166, 165f, 165t  
 mock, 177
- Calibrators, dose, 89, 89f, 189-190, 189f  
 shielding of, 189-190, 189f
- Cancer  
 bone scan of, 5t, 197  
 coregistered images of, 375  
 FDG-PET imaging of, 50, 60, 61, 341-342, 341f, 354, 355  
 gamma-ray probes in, 192-193  
 PET/CT in, 355-356, 356f  
 probe systems and, 192-193  
 radiation exposure and, 427  
 SPECT in, 305-306  
 therapy for  
   dose in, 417, 424  
    $\beta^-$  emitters in, 61
- Capillary extraction. *See* Extraction.
- Carbon-11, 450t  
 production of, 49  
 properties of, 58t
- Carbon-14, 450. *See also* Liquid scintillation counters (LSCs).
- Cardiac ejection fraction  
 calculation, with  $^{99m}\text{Tc}$ -labeled red cells, 392, 392f
- Cardiac imaging  
 with  $^{99m}\text{Tc}$ -labeled red cells, 392, 392f  
 SPECT in, 281-283, 303, 305f, 306



- Cardiac output, 393, 394
- Cardiac studies
- first-pass
    - gamma camera for, 213, 214, 392
    - labeled RBCs for, 392, 392f
    - PET for, 339
    - SPECT system for, 81
  - frame rates in, 368
  - gated, 234, 303, 304, 304f, 392, 392f
  - motion blurring in, 234, 369
  - with PET, 339
  - short axis views in, 369
  - with SPECT, 281-283, 303, 305f, 306
- Carrier-free samples, 37-38
- production of, 46
- Carrier-free specific activity (CFSA), 37-38, 56
- Carrier-mediated diffusion, 389-390, 397
- Cassen, Benedict, 2, 3f, 195
- Cathode ray tubes (CRTs), 123-124, 123f, 367
- digital image and, 367
  - hard copy derived from, 367
- Cathodes in ionization detectors, 87, 88f, 99
- Cd-109, 165t
- C-D studies. *See* Contrast-detail (C-D) studies.
- CdTe detectors. *See* Cadmium telluride (CdTe) detectors.
- Center of field-of-view (CFOV), 229-230
- Center of rotation (COR) in SPECT, 302-303
- Central processing units (CPUs), 363
- Central volume principle, 380, 394
- Kety-Schmidt method and, 395
- CERASPECT system, 280-281, 282f
- Cerebral imaging
- image co-registration and, 375-376
  - parametric, for glucose metabolism, 400, 401f
  - PET in, 330-331, 330f
  - SPECT in, 280-281, 282f, 304-305, 304f
- Cerenkov counting, 188
- Cerenkov effect, 68-70
- Cesium-137, 165t, 473
- Cesium antimony (CsSb), 98
- Cesium fluoride (CsF), 102-103
- Cesium iodide [CsI(Tl)], 100, 101t
- in compact gamma camera, 207
  - in intraoperative gamma probe, 193, 193f
- Cesium iodide [CsI(Tl)] detectors, 101t
- for cardiac SPECT, 281, 296-299
  - in gamma-ray probes, 193
- CFOV. *See* Center of field-of-view (CFOV).
- CFSA. *See* Carrier-free specific activity (CFSA).
- Chain reaction, nuclear, 43
- Chang multiplicative method, 294, 294f, 296, 297f
- Channels of multichannel analyzer, 116-118, 116f
- Characteristic x rays, 10-13, 11f, 12t
- after electron capture, 24-25
  - after internal conversion, 23
  - after ionization, 63
  - after photoelectron ejection, 74
  - in radiation detector, 151
- Charged particles. *See also* Alpha particles; Beta particles; Electrons; Positrons.
- Cerenkov effect and, 68-70
  - definition of, 63
  - energy losses and, 63-66, 67, 67f, 68, 70. *See also* Energy losses.
  - interactions with matter, 63-68, 64f, 65f, 66f, 67f, 69f, 70
  - ranges of, 70-74, 70f, 72f-73f, 73t
  - ACD and, 312-314, 313f, 314f
  - detector types and, 141
  - tracks of, 66-68, 67f
  - energy deposition along, 67-68, 67f
  - length of, 70-74, 70f, 72f-73f, 73t
- Charged-particle accelerators, 47-50, 48f-50f, 50t
- Charge-sensitive preamplifiers, 107-108, 109f
- Chelation, 58
- Chemical elements, 9. *See also* Nuclides.
- properties of, 445
  - transmutation of, 20, 21, 24, 25, 27
- Chemical properties, radioactive
- decay and, 19-20
- Chemical purity, 59
- Chemical quenching, 106, 188
- Chi square test, 133-134, 134f
- in quality assurance, 172
- Chromatography
- liquid scintillation counting with, 188
  - NaI(Tl) detector with, 182, 183f
- Chromium-51, 452
- Ci. *See* Curie (Ci).
- Cine mode, 371
- Classic method in internal radiation dosimetry, 407
- Clearance, tracer, 388
- Clearance methods for blood
- flow measurement, 394-396, 396f
- Cloud chambers, 66
- CNR. *See* Contrast-to-noise ratio (CNR).
- Cobalt-57, 165t
- Cobalt-60, 165t
- Cocktails, liquid scintillation, 105, 187
- Code of Federal Regulations, 431
- Coherent scattering, 77
- in SPECT, 297
- Coincidence circuits, 184
- Coincidence counting rates, 162-163, 322-324, 322f, 329-330
- in PET, 322-324, 322f, 329-330
  - random, 322-323, 322f, 329-330
  - correction for, 336-337
  - estimation of, 336, 340
  - scatter, 322-324, 322f, 329-330
  - correction for, 337-338
  - true, 322-323, 322f
  - uncertainty in, 336, 337
- Coincidence detection. *See also* Annihilation coincidence detection (ACD).
- of cascaded emissions, 162-163
  - efficiency of, 162-163
  - for liquid scintillation counters, 183f, 184
  - spatial resolution for, 310, 311f-312f
- Coincidence rate, 319
- Coincidence summing, 145, 146f
- Coincidence timing windows, 121, 307
- definition of, 121
  - in PET systems, 307, 322, 323, 329, 337
- Coincidence units (logic), 121-122, 184
- in PET, 307
- Cold lesions, 246, 248, 269
- Coldfinger, 97, 97f
- Collimation
- absorptive, 201, 220, 312-321, 322
  - electronic, 308
- Collimator efficiency
- of converging collimators, 225-228, 226f-227f
  - definition of, 220, 223
  - of diverging collimators, 225-228, 226f-227f
  - of parallel-hole collimators, 222, 224f, 225t
  - of pinhole collimators, 225-228, 226f-227f
  - volume sensitivity and, 301
- Collimator resolution. *See also* Spatial resolution.
- of converging collimators, 225-228, 226f-227f
  - definition of, 220, 223
  - of diverging collimators, 225-228, 226f-227f
  - of parallel-hole collimators, 220, 222, 222f, 225t
  - system resolution and, 225. *See also* Parallel-hole collimators: collimator resolution and.
  - of pinhole collimators, 225-228, 226f
  - source-to-collimator distance and, 223, 224f, 227-228, 227f-228f
  - system resolution and, 225, 227
- Collimators, 196, 196f, 201-203. *See also specific types.*
- absorptive, 201
  - cone-beam, 274-275, 274f

Collimators (*Continued*)

- converging. *See* Converging collimators.
- diverging. *See* Diverging collimators.
- fan-beam, 273-274, 274f-275f, 294, 295f, 304f
- for gamma cameras. *See* Gamma cameras: collimators for.
- multi-pinhole, 202f, 203
- parallel-hole. *See* Parallel-hole collimators.
- pinhole. *See* Pinhole collimators.
- response characteristics of, 254, 254f
- sensitivity of, 231
  - in gamma camera, 223, 224f, 225t, 227, 231
  - lesion detectability and, 246, 247f
  - septal thickness in, 203, 203f, 211, 220-221, 220f-221f
  - slant-hole, 203
- Collisional energy losses, 64-65, 66f-67f
  - rate of, 66-68, 69f
- Collisions of charged particles with matter, 63-64, 64f
- Colloids, <sup>99m</sup>Tc-labeled, 192-193
- Color displays, 367, 368f
- Color quenching, 106
- Combined-modality imaging. *See* Hybrid imaging systems.
- Comparators, 113
- Compartmental models, 390-392, 390f-391f. *See also* Tracer kinetic modeling: compartments in.
  - basic concepts of, 380, 382, 384f
  - for FDG, 396, 397
  - formulation of, 390-392, 390f, 391f
  - Renkin-Crone model vs., 389f, 390-391
- Competitive ( $\beta^+$ , EC) decay, 26
- Compton edge, 143, 143f, 144, 146, 151
- Compton region, 143, 143f, 145, 147
- Compton scattering, 74-78, 75f-77f, 75t, 78t, 104. *See also* Scattered radiation.
  - in gamma camera studies
    - energy resolution and, 209, 211-212
    - spatial resolution and, 209, 210
  - intrinsic spatial resolution and, 209-211, 210f-211f
  - in PET, 322-323, 322f, 329-330
    - correction for, 337-338
  - photon attenuation and, 79, 80f-81f
  - in radiation detectors, 141-143, 142f-143f
    - gamma-ray energy and, 146-147, 147f
    - nonlinearity and, 148
    - scintillator materials and, 102, 103, 104
  - in SPECT, 296-299

Compton scattering (*Continued*)

- in tissue
  - detection efficiency and, 163-164, 164f
  - downscatter derived from, 296-297, 297f
  - probe measurements and, 192
  - in x-ray CT, 349
- Computed tomography (CT), 253. *See also* Hybrid imaging systems; Positron emission tomography (PET); Single photon emission computed tomography (SPECT); X-ray computed tomography.
  - emission, 253. *See also*
    - Reconstruction tomography; Tomographic imaging.
  - advantages of, 269-270
  - image quality in, 263-270
    - for low-contrast lesions, 269-270
    - noise in, 266-268
  - in multimodality
    - instrumentation, 4-5
    - transmission, 253
- Computer networks, 367, 378
- Computer observer performance studies, 233
- Computers, 363. *See also* Digital image processing; Digital images; Tomographic imaging.
  - contrast enhancement algorithms of, 242
  - dead time losses in, 168
  - in gamma camera SPECT
    - system, 280
  - in liquid scintillation counting systems, 183f, 184, 189
  - pixelation effects caused by, 234
  - in well-counter systems, 178, 181
- Concrete shielding, 437
- Cone-beam collimators, 274-275, 274f
- Cone-beam reconstruction, 273-275, 274f
- Confidence intervals, 127, 127t
- Conjugate counting, 287-291, 287f, 288f, 289f, 290f, 291t, 292f, 292t, 293
- Conjugate variables, 481
- Consistency requirements in reconstruction tomography, 266, 266f-267f
- Constant fraction timing, 115-116
- Contaminants
  - detection of, by curve stripping, 39
  - effects of, 58
    - in <sup>99m</sup>Tc, 53, 58
- Contrast, 233, 239-240, 243-247
  - background counting rates and, 239-240
  - definition of, 233, 239
  - with gamma camera
    - energy resolution and, 214
    - pulse pile-up and, 213, 214, 214f
  - of hot vs. cold lesions, 246, 248
  - in image display, 369, 370f

Contrast (*Continued*)

- information density and, 243-244
  - lesion size and, 243-244, 245
  - modulation transfer function and, 236, 237f
- in PET, 241-242, 253, 336, 337, 346
- Rose criterion for, 244, 269
- scattered radiation and, 240-241, 242f
- septal penetration and, 240-241, 242f
- spatial resolution and, 243, 246, 247f, 249f
- in SPECT, 241-242, 243f, 253
- Contrast agents
  - artifacts from, in PET/CT and SPECT/CT attenuation correction, 359-360
    - for x-ray CT, 349-350
    - artifacts from, 359-360
- Contrast enhancement, 242-243
- Contrast-detail (C-D) studies, 247-249, 248f-249f
- Contrast-to-noise ratio (CNR), 243-247. *See also* Noise.
  - in reconstruction tomography, 266-268
  - in tomographic imaging, 253, 266, 269-270
- Control rods, 43-44
- Converging collimators, 204, 204f
  - advantages and limitations of, 228
  - efficiency of, 225-228, 226f-227f
  - performance characteristics of, 225-228, 226f-227f
  - resolution of, 225-228, 226f-227f
    - source-to-collimator distance and, 228, 228f
  - in SPECT, 279-280
- Conversion electrons, 22-24, 23f
- Converter for proportional counter, 159
- Convolution, 489-492, 490f, 491f, 492f
  - backprojection and, 258
  - smoothing filter and, 373
- Convolution theorem, 492
- Copper-62, 454
- Copper-64, 455
- COR (center of rotation) of SPECT system. *See* Center of rotation (COR) in SPECT.
- Co-registration, 375-376, 377f
- Coronal sections, orientation of, 369, 370f
- Correlation coefficient, 139-140
- Cosmic rays, 177-178, 432
- Cost function, 271
- Coulombic forces, 14
- Count skimming, 218
- Counter paralysis, 169. *See also* Paralyzable counting systems.
- Counters, digital, 119-121, 120f
- Counting, energy-selective. *See* Energy-selective counting.
- Counting curves for Geiger-Müller counters, 94, 95f

- Counting losses in gamma camera, 213-214, 213f, 215f, 230
- Counting rates, 130  
in annihilation coincidence detection, 321  
background, 131  
for calibration sources  
absolute activity assays and, 177  
detection efficiency and, 164  
mock sources and, 177  
coincidence. *See* Coincidence counting rates.  
crosstalk and, 178-179  
dead time losses and, 168-171  
detection efficiency and, 155  
with absorbing medium, 163  
with cascaded emissions, 162-163  
with full-spectrum counting, 159, 163  
with scattering medium, 163  
differences between, 130-131  
with energy-selective counting, 159  
estimation of, 132  
of gamma camera, 213-216, 230  
with multiple radionuclide sources, 178-179  
noise equivalent, 340-341, 341f  
observed vs. true, 168-169, 168f-169f  
optimal division of, 133  
for paralyzable vs. nonparalyzable counting systems, 168-169, 168f-169f  
in pulse-height spectrometry, 146, 147f  
of SPECT system, 302  
statistical significance of, 130-131  
total-spectrum, 170  
uncertainty in, 130, 131, 132, 133
- Counting statistics. *See* Statistical analysis.
- Counting systems, 173-194  
for Cerenkov counting, 188  
comparison of, 132  
components of, 107, 108f, 173  
dead times of, 168-171  
detectors for, 173  
conventional NaI(Tl), 182  
gas-filled, 189-190  
gas-flow counters in, 190  
liquid scintillation, 182-189. *See also* Liquid scintillation counters (LSCs).  
NaI(Tl) well counters in, 173-182, 174f, 174t. *See also* NaI(Tl) well counters.  
paralyzable vs. nonparalyzable, 168-169  
probe  
miniature beta particle, 194  
miniature gamma-ray, 192-194, 193f  
NaI(Tl), 192, 192f  
quality assurance for, 171-172  
semiconductor, 190-192, 191f  
in vitro, 173
- Counting systems (*Continued*)  
in vivo, 173, 192-194  
whole-body, 194  
Counting time, statistical reliability and, 132-133  
Counting vials, 184-185  
Count-rate performance in SPECT, 302  
Coverage requirements in reconstruction tomography, 266, 266f-267f  
CPUs. *See* Central processing units (CPUs).  
CR differentiation circuit, 111-112, 111f-112f  
Cristy-Eckerman phantoms, 414, 414f, 415t  
Cross section  
activation, 53-54, 54f  
neutron-capture, 45-47, 46t  
Cross-plane data acquisition, 332, 333f  
Crosstalk  
in liquid scintillation counting, 184, 185, 187, 187f  
between projection elements, 286  
in well-counter measurements, 178, 178f, 179, 181-182  
CRTs. *See* Cathode ray tubes (CRTs).  
CsF. *See* Cesium fluoride (CsF).  
CsI(Tl). *See* Cesium iodide [CsI(Tl)] detectors.  
CsSb. *See* Cesium antimony (CsSb).  
CT. *See* Computed tomography (CT).  
Cumulated activity, 409-412, 410f, 411f  
average absorbed dose and, 408, 414, 417, 424  
calculation of, 424  
mean dose per, 411f, 414f, 415-416, 418t-423t  
for  $^{18}\text{F}$ , 415-416, 422t-423t  
for  $^{131}\text{I}$ , 415-416, 420t-421t  
for  $^{99\text{m}}\text{Tc}$ , 415-416, 418t-419t  
problems in determination of, 424  
in source organ, 409-410, 424  
Curie (Ci), 32  
Curie, Marie, 2  
Curve stripping, 39  
Cut-off frequency in PET, 319  
Cyclotrons, 47-49, 48f-49f, 50t  
negative-ion, 48-49, 49f  
principles and design of, 47-49, 48f-49f  
radionuclides produced in, 49-50, 50t  
in cyclotrons, 47-50, 50t  
CZT detectors. *See* Cadmium zinc telluride (CZT) detectors.
- D**  
(d, n) reaction, 47, 50t  
Dalton (Da), 8  
Dalton, John, 9  
Dark adaptation of samples, 185  
Daughter nucleus, 19  
De Hevesy, Georg, 2
- Dead time/dead time losses, 168-171, 168f, 169f, 171f  
apparent, 213, 213f, 214  
determination of  
fixed-rate pulser method for, 171, 171f  
two-source method for, 171, 171f  
in gamma cameras, 213-214, 213f, 230  
correction methods for, 213-214  
in Geiger-Müller counters, 188  
in liquid scintillation counters, 168  
mathematical models of, 168-169  
in NaI(Tl) well counters, 179  
in paralyzable vs. nonparalyzable systems, 168-169, 168f-169f  
percentage, 169  
in PET, 326, 330, 332, 339, 340  
in SPECT, 302  
window fractions and, 170, 213, 213f
- Decay. *See* Radioactive decay.  
Decay constant, 31, 32  
average lifetime and, 34  
definition of, 31  
half-life and, 33-34  
Decay curve, universal, 35, 35f  
Decay factors, 32-33, 33f  
approximation to, 32, 32f, 33  
determination of, 34-35  
effective, 35-37, 36f  
tables of, 34, 34t  
Decay rate. *See* Activity.  
Decay scheme diagrams, 20-21, 20f  
of important radionuclides, 449, 449f-475f  
Decay series, 27-28, 27f  
Decay time of scintillators, 101t, 104  
Decontamination measures, 439  
Deep-dose equivalent, 431-432  
Degrees of freedom, 136, 136f, 140  
Delayed window method, 336-337  
Delay-line methods, 111, 113  
Delta ( $\delta$ ) rays, 63, 66, 67f  
Density of absorbers  
attenuation coefficient and, 78-79  
energy losses and, 65  
range of alpha particles and, 71  
range of electrons and, 72, 73, 73f  
range of positrons and, 314  
Dental implants, artifacts from, 360  
Deoxyglucose method, 397, 400  
Depreotide,  $^{99\text{m}}\text{Tc}$ -labeled, 305  
Depth-of-interaction (DOI) effect, 316-318, 317f, 326, 329, 330, 331  
Derandomizers, 213-214  
Derived quantities, 7

Detectability. *See also* Phantoms.  
 of cold vs. hot lesions, 246, 248, 248f, 297  
 contrast-to-noise ratio and, 243-244  
 in emission computed tomography, 269-270  
 information density and, 244-245, 246  
 observer performance studies of, 247, 248, 249f, 250-251, 250f  
 Rose criterion for, 244, 269  
 size and, 244, 245, 246, 247  
 spatial resolution and, 246-247, 247f

Detection efficiency, 155-166  
 attenuation and, 156, 160-164  
 calibration sources and, 164-166, 165f, 165t  
 cascaded gamma emissions and, 162, 163  
 in coincidence detection, 162-163  
 complicating factors in, 160-164, 160f, 161f, 164f  
 components of, 155-156  
 definition of, 156  
 edge effects and, 160  
 emission rates and, 155  
 energy-selective counting and, 156, 159  
 factors affecting, 155-156  
 of gamma camera, 211, 212f  
 detector thickness and, 211, 212f  
 nonuniformity and, 217  
 used for PET, 329-330  
 of gamma cameras  
 detector thickness and, 211, 212f  
 nonuniform, 217  
 of gas flow counter, 190  
 geometric, 156, 157f-158f  
 of absorptive collimators, 321  
 edge effects on, 160  
 of gas flow counter, 190  
 of liquid scintillation counters, 157  
 of NaI(Tl) detectors, 156, 182  
 in whole-body counter, 194  
 of NaI(Tl) well counters, 157, 174, 175  
 of PET systems, 319-322, 330, 331, 334  
 of semiconductor detector, 190-191  
 housing of detector and, 164  
 intrinsic, 156, 158-159, 159f  
 calibration and, 164  
 of coincidence detector, 310, 311f, 312, 315, 319  
 definition of, 156  
 of gas-filled detectors, 158-159  
 of NaI(Tl) detectors, 158-159  
 nonuniform attenuation and, 160-162, 161f, 162f  
 of semiconductor detectors, 158  
 of well-counter detector, 174, 175f

Detection efficiency (*Continued*)  
 of liquid scintillation counter, 157, 185  
 of NaI(Tl) conventional detector, 156, 182  
 of NaI(Tl) well counter, 157, 174, 175, 175f-176f, 179  
 nonuniform, 160-162, 160f-161f  
 of PET systems, 324  
 Compton scattering and, 337  
 normalization corrections to, 335-336  
 in phantoms, 166  
 photofraction and, 159, 160f  
 photopeak and, 163  
 radiation absorption and, 156  
 radiation scatter and, 156, 163-164  
 scatter outside of detector and, 144, 163-164, 164f  
 of semiconductor detectors, 151, 158, 164, 190  
 total, 160-161, 160f  
 Detector scatter events, 204-205  
 Detectors. *See* Radiation detectors.  
 Detergents for LS sample preparation, 187  
 Deuterons in cyclotron, 47, 48  
 DF. *See* Decay factors.  
 DFT. *See* Discrete Fourier transform (DFT).  
 DICOM. *See* Digital Imaging and Communications in Medicine (DICOM).  
 Diethylenetriamine penta-acetic acid (DTPA), 5t, 60t, 381t, 479  
 Differential spatial linearity, 229-230  
 Differential uniformity, 229-230  
 Differentiation circuits, 111-112, 111f-112f  
 Diffusion, carrier-mediated, 389, 390, 395, 397  
 Diffusion constant, 389  
 Digital counters, 119-121, 120f  
 Digital image processing, 363-378.  
*See also* Digital images.  
 acquisition modes in, 367-369  
 frame-mode, 367-368  
 gated imaging, 245, 369  
 list-mode, 368-369  
 archival systems for, 378  
 binary numbers in, 364-365  
 computer processors for, 363  
 definition of, 363  
 display in  
 cathode ray tube, 367  
 hard copy, 367  
 liquid crystal, 367  
 edge detection in, 373-375  
 equipment for, 376-378  
 file format standards for, 378  
 for gamma camera images, 364  
 detector area and, 364, 365f  
 image arithmetic in, 371  
 image co-registration in, 375-376, 377f

Digital image processing (*Continued*)  
 image display in, 367  
 color, 367, 368f  
 grayscale, 367, 370f  
 image segmentation in, 373-375, 377f  
 in CT-based attenuation correction, 357  
 image smoothing in, 373, 375f  
 image visualization in  
 orientation of sections in, 369, 370f  
 parametric images and, 372  
 projection tool for, 369-371, 371f  
 surface rendering in, 369-371  
 windowing in, 369, 370f  
 Laplacian technique in, 373-375  
 linear sampling distance and, 365-366  
 matrix size in, 365  
 microprocessors for, 363  
 for multislice tomographic images, 364  
 networks for, 378  
 overview of, 363  
 pixel depth in, 365  
 pixels in, 364, 364f. *See also* Pixels.  
 regions of interest in, 372-373, 372f  
 spatial resolution and, 365-367, 366f. *See also* Spatial resolution.  
 steps in, 376-378  
 techniques of, 369-376  
 co-registration in, 375-376, 377f  
 edge detection in, 373, 375, 376f  
 image smoothing in, 373, 375f  
 regions of interest in, 372-373, 372f  
 segmentation in, 373, 375, 377f  
 time-activity curves in, 373, 374f  
 visualization tools in, 369, 370f, 371-372, 371f, 372f  
 terminology for, 364-365  
 time-activity curves and, 365, 374f  
 visualization tools for, 369-372, 370f-372f  
 volume of interest in, 373  
 voxels in, 364  
 Digital images, 364-369. *See also* Image quality.  
 acquisition modes of, 367-369  
 archiving of, 378  
 basic characteristics of, 364-365, 364f, 365f  
 computer networks for management of, 378  
 display of  
 image structure and, 367, 368f  
 spatial resolution and, 365-367, 366f



- Digital images (*Continued*)  
 technologies for, 119-121, 119f, 120f, 121  
 visualization tools for, 367, 368f  
 file formats for, 378  
 gamma camera and, 197, 364, 365f, 482  
 hard copy of, 367  
 parametric, 372  
 retrieval of, 376, 378  
 spatial resolution of, 365-367, 366f  
 terminology of, 364-365, 364f, 365f
- Digital Imaging and Communications in Medicine (DICOM), 378
- Digital signal processors, 363
- Digitization, 117-118, 363
- Di-isopropyl naphthalene (DIN), 105, 187
- Dilution principle, 382-383
- Dilution quenching, 106
- DIN. *See* Di-isopropyl naphthalene (DIN).
- Direct Fourier transform  
 reconstruction, 258-260, 259f-260f. *See also* Reconstruction tomography.  
 image quality in, 263-270  
 sampling in, 263-265
- Direct substitution, 59-60
- Discrete Fourier transform (DFT), 482
- Discriminators, 114, 115f, 118, 121, 121f  
 of gamma camera, 201, 205  
 lower-level, 113, 114f  
 upper-level, 113, 114f
- Disintegrations per second (dps), 31
- Disposal of radioactive waste, 439
- Distribution volume, 382-383, 384f  
 blood flow measurement and, 393
- Diverging collimators, 202f, 203  
 advantages and limitations of, 228  
 efficiency of, 225-228, 226f-227f  
 performance characteristics of, 225-228, 226f-227f  
 resolution of, 225-228, 226f-227f  
 source-to-collimator distance and, 228, 228f
- DMSA (2,3-dimercaptosuccinic acid), 60t
- DOI. *See* Depth-of-interaction (DOI) effect.
- DOPA, <sup>18</sup>F-Fluoro, 372f, 373, 374f, 381t
- Dose. *See* Radiation dose;  
 Radiation dosimetry, internal.
- Dose calibrators, 89, 89f, 189-190, 189f  
 shielding of, 189-190, 189f, 437
- Dose equivalent. *See* Effective dose equivalent; Equivalent dose.
- Dose limits, 431-432
- Dose reciprocity theorem, 415
- Dose-equivalent rate, 435
- Dose-modifying factors, 428
- Dose-rate constant, 434-435, 435t
- Dosimeters  
 badge, 440, 440f  
 pocket, 89-90, 90f, 440  
 ring, 440, 440f
- Dosimetry, internal radiation. *See* Radiation dosimetry, internal.
- Double differential shaping, 112, 112f
- Double escape peaks, 144, 145f
- Downscatter during transmission scan, 296, 297f
- Dps. *See* Disintegrations per second (dps).
- DTPA (diethylenetriamine penta-acetic acid), 5t, 60t, 381t, 480
- Dynamic imaging, 392-403. *See also* Cardiac studies; Tracer kinetic modeling.  
 in blood flow measurement, 379-386, 394-396. *See also* Blood flow: measurement of.  
 in cardiac imaging, 392. *See also* Cardiac imaging.  
 in enzyme kinetic studies, 396-401  
 with gamma camera, 197, 206-207, 207f  
 in glucose metabolism studies, 396-401  
 with PET, 335  
 in receptor binding studies, 402  
 in receptor ligand assays, 401-403, 402f, 404f  
 with SPECT, 279-278, 284, 286f, 305f, 306  
 in receptor binding studies, 402
- Dynodes, 98-99, 98f
- E**
- EC. *See* Electron capture (EC).  
 (EC,  $\gamma$ ) decay, 24-25  
 competitive, 26
- ECD. *See* Ethyl-cysteine-dimer (ECD).
- ECT. *See* Emission computed tomography (ECT).
- Edge detection, 373, 375, 376f
- Edge effects, 160
- Edge packing, 217, 229
- Edge sharpness, 237, 260-261
- Effective atomic number, 65, 101t, 103-104
- Effective decay factors, 35-37, 36f
- Effective dose, 417, 425t, 429t  
 from background radiation, 427  
 recommended limits for, 434t
- Effective dose equivalent, 417, 428, 429t, 432, 434t, 435. *See also* Equivalent dose.  
 regulatory limits for, 431-432  
 for selected  
 radiopharmaceuticals, 478-479
- Effective half-life, 411-412
- Effective positron range, 313, 313f
- Efficacy studies, 250-251
- Efficiency. *See* Collimator efficiency;  
 Detection efficiency.
- e/ $\gamma$  conversion ratio, 24
- Ejection fraction, 392, 392f
- Electrical forces, 14
- Electromagnetic radiation, 8-9, 66.  
*See also* Gamma rays; Photons;  
 X rays.
- Electromagnetic spectrum, 8-9, 8f
- Electrometers, 89  
 in dose calibrators, 89, 89f  
 in survey meters, 89-91, 89f
- Electron capture (EC), 24-25  
 competitive with positron emission, 27, 27f, 26, 26f  
 by cyclotron-produced radionuclides, 49, 50t  
 in (EC,  $\gamma$ ) decay, 24-25, 24f  
 line of stability and, 28  
 by reactor-produced radionuclides, 49, 46, 46t
- Electron gun, 123
- Electron multiplication factor, 148-149
- Electron shells, 9, 14
- Electron volt (eV), 8
- Electronic collimation, 308
- Electronic instrumentation, 107-124  
 amplifiers in, 110-113, 110f, 111f, 112f  
 dead time and, 168, 170  
 in nuclear instrument module, 122-123  
 in rate meter, 120  
 coincidence units in, 121-122, 121f  
 for PET scanner, 307-308  
 counters and rate meters in, 119-121, 119f, 120f, 121f  
 detectors in. *See* Radiation detectors.  
 display technologies in, 123-124, 123f  
 high-voltage power supplies in, 122  
 NIM (modular) systems in, 122-123  
 preamplifiers in, 107-110, 108t, 109f  
 of gamma camera, 219  
 pulse-height analyzers in. *See* Pulse-height analyzers (PHAs).  
 time-to-amplitude converters in, 118-119, 119f
- Electronic noise. *See also* Noise;  
 Signal-to-noise ratio (SNR).  
 counting uncertainty and, 131  
 energy resolution and  
 with scintillation detectors, 148, 149, 150, 150f  
 with semiconductor detectors, 152, 152f  
 in liquid scintillation counters, 184, 185, 186  
 power supply and, 122  
 pulse shaping and, 110-111, 111f

- Electronic noise (*Continued*)  
 reduction by coincidence detection, 184  
 spectral blurring and, 148
- Electrons. *See also* Beta particles; Charged particles.  
 annihilation of, after pair production, 78, 78t  
 Auger, 10-13, 12f, 23, 24, 63, 74, 78t  
 binding energy of, 9-10, 11f  
 in Bohr atom, 9, 10f  
 Cerenkov effect and, 68-70  
 conversion, 22-24, 23f  
 decay modes involving, 20-22, 20f, 21f, 22f, 23f  
 energy losses by, 63-70. *See also* Energy losses.  
   rate of, 66-68, 69f  
 energy-level diagram of, 10, 11f  
 Exclusion Principle for, 9  
 interactions with matter, 63-70  
   Cerenkov effect in, 70  
   energy deposition in, 67-68, 67f, 77-78, 77f, 78t  
   by photoelectrons, 74, 74f  
   ranges in, 74, 75  
   photon MFP vs, 82t  
   tracks in, 66-67, 67f  
 mass-energy equivalence and, 8, 16  
 notation for, 12-13  
 orbits of, 9, 10f  
 pair production and, 76-77, 77f.  
   *See also* Pair production.  
 as particulate radiation, 8  
 photoelectron as, 74, 74f.  
   *See also* Photoelectric effect.  
 properties of, 13t  
 radiation from, 10-13, 11f-12f, 12t  
 range of, 71-72, 82t  
 recoil, 74-76, 75f, 75t, 78t, 144  
 pulse-height spectrum and, 142, 144  
 in Rutherford atomic model, 9  
 secondary, 63, 64f, 66, 67f, 78t  
   in photomultiplier tubes, 98-99, 100f  
 substates of, 9  
 tracks of, 66-67, 67f  
   energy deposition along, 67-68  
   length of, 70, 70f, 72f-73f  
 x-ray emission and. *See* Characteristic x rays.
- Elements, 9
- EM (expectation-maximization) algorithm, 272
- Embryo, dose limits for, 432
- Emission computed tomography (ECT), 253. *See also* Reconstruction tomography; Tomographic imaging.  
 advantages of, 269-270  
 image quality in, 263-270  
 for low-contrast lesions, 269-270  
 noise in, 266-268
- Emission rates, 155
- Emission scans with SPECT, 296
- Emissions  
 cascaded, coincidence detection of, 162-163  
 inverse-square law and, 156, 157f  
 isotropic, 156
- Emission/transmission scans, simultaneous, in PET  
 attenuation correction, 338-339
- Energy  
 binding  
   electron, 9-12  
   nuclear, 15-18, 17f  
   mass and, 8, 15-16, 19  
   of photon, 8  
   transition, 19  
   units of, 7-8  
 Energy corrections for gamma camera, 217-218  
 Energy deposition  
   by charged particles, 63-66, 67, 67f, 68, 70  
   dose and. *See* Radiation dose; Radiation dosimetry, internal.  
   by photons, 64, 77-78, 77f, 78t  
   in radiation detectors, 91  
 Energy levels  
   of electrons, 10, 10f  
   of nucleus, 13, 13t, 15-16  
 Energy linearity, 147-148, 148f  
 calibration for, 147-148, 148f  
   with well counter, 178  
 energy resolution and, 148-151
- Energy losses, 63-64, 66  
 collisional vs. radiation, 64-65, 66f-67f  
 linear energy transfer and, 68  
 linear stopping power and, 68  
 rate of, 66-68, 69f  
 specific ionization and, 68
- Energy resolution.  
 of crystal scintillation detectors, 148-151, 149f, 150f  
 definition of, 148-149  
 electronic noise and, 148, 149, 150, 150f  
 energy linearity and, 147-148  
 factors affecting, 148-151  
 of gamma cameras, 150, 201, 211-213, 212f, 231  
   measurement of, 231  
 integration time and, 150  
 of liquid scintillation detectors, 153, 153f  
 of NaI(Tl) detectors, 148-151  
 of PET detectors, 337  
 photoelectron production and, 149-150  
 of proportional counters, 151, 153  
 quality assurance and, 172  
 of semiconductor detectors, 151-152, 152f, 190-192, 191f, 240  
 in SPECT, 302  
 spectral blurring and, 144, 148-151  
 statistical variations and, 148-150
- Energy response curve for survey meters, 90-91, 91f
- Energy spectrometry. *See* Pulse-height spectrometry.
- Energy window  
 of gamma camera, 212, 212f, 213, 218, 218f  
   for PET, 336, 337  
 image contrast and, 240, 241f  
 with NaI(Tl) detectors, 240  
 volume sensitivity and, 301-302
- Energy-mass conversion in radioactive decay, 19
- Energy-selective counting, 156, 159, 160f  
 cascaded gamma emissions in, 164  
 detection efficiency and, 156, 159  
 in gamma camera, 200, 201f  
 scattering medium in, 163  
 window fraction effect in, 170-171
- Energy-sensitive detectors, 107, 108, 109, 111, 113. *See also* Proportional counters; Scintillation detectors; Semiconductor detectors.
- Entrance windows, 98, 98f, 101-102, 104  
 thickness of, 166-167
- Enzyme kinetics, 396-401  
 in carrier-mediated diffusion, 390  
 glucose metabolism and, 396-401, 397f, 398f, 401f  
 Michaelis-Menten hypothesis and, 396-397, 397f
- Enzyme-substrate complex, 385, 385f, 397
- Equilibrium absorbed dose constant, 412-413
- Equilibrium dissociation constant, 401
- Equilibrium methods for blood flow measurement, 393
- Equilibrium models, 386
- Equivalent dose, 407-408, 429t.  
*See also* Effective dose equivalent.  
 air kerma and, 435-436  
 distance from source and, 435-436  
 dose-equivalent rate and, 435  
 recommended limits for, 431-432, 434t  
 units of, 407-408, 428
- Error. *See also* Statistical analysis.  
 propagation of, 128-130  
 types of, 125-126
- Escape peaks, 144, 145f  
 iodine, 144, 144f
- Ethyl-cysteine-dimer (ECD), 5t, 60t, 304
- Euler's equation, 482
- eV. *See* Electron volt (eV).
- Event detection in gamma cameras, 204-206, 205f
- Exchange forces, 14-15

- Excitation, 63-64, 87  
 by charged particles, 63, 64, 64f  
 after photon interactions, 78  
 in radiation detection, 87  
 by Geiger-Müller counter, 92  
 by organic scintillator, 105
- Excited states  
*See* Excitation.
- nuclear, 14, 15  
 in ( $\beta^-$ ,  $\gamma$ ) decay, 21, 22, 22f  
 in in ( $\beta^+$ ,  $\gamma$ ) decay, 25  
 in (EC,  $\gamma$ ) decay, 24
- Exclusion Principle, 9
- Excretion  
 of accidentally ingested  
 radioactive material, 437  
 cumulated activity and, 409, 410,  
 411, 411f, 412
- Expectation-maximization  
 reconstruction, 272-273
- Exponential decay, 32-34, 32f-33f
- Exponential functions, properties  
 of, 33, 34, 35
- Exposure, radiation, 428-431, 429t
- air kerma and, 428-431, 429t,  
 438-439  
 definition of, 429-430  
 minimizing duration of, 436  
 TDS rules and, 436  
 units of, 428-431, 429t
- Exposure rate, 89, 428-431
- External beam radiation, 48
- Extraction, 386-388, 387f, 388f,  
 389f, 390-391, 390f
- Extraction coefficient, 388
- Extrapolated range, 71-74, 72f-73f  
 of electrons, 71-73, 72f, 73f, 74  
 of positrons, 312-314
- Extrinsic uniformity for gamma  
 cameras, 229-230
- F**
- $f$  factor, 430, 430f
- False-positive fraction (FPF), 249,  
 250f
- Families, nuclear, 14, 14f
- Fan-beam collimators, 273-274,  
 274f-275f, 294, 295f, 304f
- Fan-beam projections in PET, 320f,  
 321
- Fan-beam reconstruction, 273-276,  
 274f-275f
- Fast Fourier transform (FFT), 482,  
 485
- FBP. *See* Filtered backprojection  
 (FBP).
- FDG. *See* Fluorodeoxyglucose  
 (FDG).
- FDG model for glucose metabolism,  
 397-401, 398f
- FDG-PET, 341-342, 342f  
 with CT, 355-356, 356f  
 with MRI, 360-361, 361f
- Feldkamp algorithm, 275
- Fetus, dose limits for, 432, 433,  
 434t
- $^{18}\text{F}$ -2-fluoro-2-deoxy-D-glucose. *See*  
 Fluorodeoxyglucose (FDG).
- FFT. *See* Fast Fourier transform  
 (FFT).
- Fick principle, 387, 395
- Field-effect transistors, 109
- Field-of-view (FOV)  
 Fourier transform and, 482, 483,  
 483f, 487  
 image quality and, 262, 263, 265,  
 266  
 in PET, 318, 319, 321, 323, 329,  
 335  
 axial, 326, 328, 332, 335  
 with gamma camera, 332  
 with three-D acquisition, 332,  
 334  
 pixel size and, 364, 365  
 in SPECT, 279, 280, 281  
 for performance  
 measurements, 301, 302  
 for transmission scan, 295  
 useful, 217, 229, 230, 231  
 in PET, 319, 321
- File format standards, 378
- Film  
 analog images on, 364  
 spatial resolution on, 233-234  
 transparency, hard-copy images  
 on, 367
- Film badge, 440
- Filtered backprojection (FBP),  
 260-262, 260f, 261f, 262f. *See*  
*also* Reconstruction  
 tomography.  
 attenuation correction to, 293  
 for fan-beam data, 274  
 image quality in, 263, 264f,  
 265-270, 265f, 266f, 267f  
 iterative reconstruction vs.,  
 270-271  
 limitations of, 262  
 noise in, 260-261, 263, 264f, 293f  
 for PET data, 332  
 sampling in, 263-265  
 simple backprojection vs.,  
 260-261  
 steps in, 260, 261f
- Filters  
 reconstruction, 260-261, 263,  
 264f  
 Hann, 261, 262f  
 in PET, 319  
 ramp, 260-261, 261f-262f  
 in SPECT, 301  
 Shepp-Logan, 261, 262f,  
 263-265, 264f  
 smoothing, 373
- First-order kinetics, 384, 390
- First-order rate constants, 384-385,  
 385f
- Fission  
 radioactive decay by, 28  
 radionuclide production by,  
 43-47  
 in reactors, 43-44
- Fission fragments, 28, 44-45, 45f
- Fission moly generators, 53
- Fission neutrons, 28, 43, 53
- Flat-panel display, 124
- Floating point numbers, 365
- Flood source, 294, 295f
- Flood-field images, 216f, 217  
 from block detector, 324, 325f  
 checks of, 229, 230
- Flood-field images (*Continued*)  
 corrected, 217-218, 218f, 219f  
 in SPECT, 302
- Flow counting  
 with liquid scintillation counters,  
 188  
 with NaI(Tl) detectors, 182
- Flow rate, tracer measurement of,  
 380, 380f
- Fluor, 105, 106
- Fluorescent yield, 12, 13f
- Fluorine-18  
 characteristics of, 451  
 decay of, 26, 27, 451  
 detection of, with CZT  
 spectrometer, 151, 153f  
 in FDG labeling, 49-50  
 labeling with, 60-61  
 mean dose per cumulated  
 activity for, 415-416,  
 422t-423t  
 positron range of, 314, 314f, 315  
 production of, 46-47, 49-50  
 properties of, 58t
- Fluorodeoxyglucose (FDG), 61  
 advantages of, 60  
 as analog tracer, 382  
 clinical uses of, 5, 5t, 60, 61,  
 341-342, 342f  
 co-registered images with, 377f  
 $^{18}\text{F}$  labeling of, 49-50  
 kinetics in metabolism of, 396,  
 397-400, 398f  
 production of, 50  
 radiation dose estimates for,  
 425t, 427, 478, 479
- Flux, 383-384  
 steady state and, 385-386, 386f
- Flux density, 54, 55f
- Focal spot, 347
- Forward projection, 270-272, 270f,  
 276
- Fourier slice theorem. *See*  
 Projection slice theorem.
- Fourier transform (FT), 258  
 basic concept of, 481, 482f  
 calculation of, 258  
 of convolution, 492  
 definition of, 258  
 direct, 258-260. *See also* Direct  
 Fourier transform  
 reconstruction.  
 examples of, 487f, 487, 488f  
 inverse, 258  
 modulation transfer function  
 and, 238, 481, 485f, 492  
 properties of, 483-485, 483f,  
 487  
 in tomographic reconstruction  
 for 3-D PET data, 334  
 direct, 258-260, 259f
- FOV. *See* Field-of-view (FOV).
- FPF. *See* False-positive fraction  
 (FPF).
- Frame-mode acquisition, 367-368
- Free-response operating  
 characteristics (FROC), 250
- Frequency, 8
- Frequency distributions, 126, 127f  
 Gaussian, 127f, 128  
 Poisson, 126, 127f, 128

Frequency response curves, 236-237, 236f  
 FT. *See* Fourier transform (FT).  
 Full width at half maximum (FWHM).  
   computation of, 149, 149f  
   definition of, 148-149  
   of gamma camera image  
     collimator resolution and, 222, 222f, 227  
     intrinsic resolution and, 210-211, 221, 225t, 229  
     system resolution and, 225, 229, 235-236  
   of Gaussian function, 491-492  
   linear sampling distance and, 263, 265  
 in PET  
   of angular distribution, 319  
   partial-volume effects and, 340  
   of positron range, 312f, 314, 314f, 316  
   of spatial resolution, 310, 311f, 317, 318  
 pixel size and, 234, 366  
 in reconstruction tomography, 263  
 in resolution evaluation, 235-236  
 in SPECT  
   partial-volume effects and, 299, 300f  
   reconstruction tomography and, 301-302  
   of spatial resolution, 301  
 Full width at tenth maximum (FWTM)  
   of gamma camera image, 229  
 Fundamental quantities, 7  
 FWHM. *See* Full width at half maximum (FWHM).  
 FWTM. *See* Full width at tenth maximum (FWTM)

## G

Gadolinium-153, transmission scan with, 295, 296, 297f  
 Gadolinium oxyorthosilicate (GSO)  
   in PET detectors, 322t, 326  
   properties of, 101t  
 Gain factor  
   for amplifiers, 110  
   drift in, in gamma camera, 219-220, 220f  
   for preamplifiers, 108-109  
 Gallbladder, gamma camera imaging of, 207f  
 Gallbladder dynamics, tracers for, 381t  
 Gallium-67, 5t, 58t, 243, 305, 478  
 Gallium-68, 313t, 315f, 316, 328, 457  
 Gamma cameras, 195-208  
   acceptance testing for, 228-231  
   analog, 197-200  
   analog buffers for, 213-214  
   in annihilation coincidence detection, 310-312, 311f  
   calibration of, 147-148  
   clinical uses of, 1, 206-208, 206f, 207f, 208f

Gamma cameras (*Continued*)  
   collimator efficiency and, 220  
   collimator resolution and, 220, 222, 225t  
   collimators for, 196, 196f, 201-204, 202f, 203f, 204f  
     absorptive, 201  
     converging, 204, 204f  
     design and performance of, 220-223, 221f, 222f, 224f, 225, 225t, 226f, 230  
     diverging, 202f, 203  
     modulation transfer functions of, 236, 237f, 238f, 239f  
     multi-pinhole, 202f, 203  
     parallel-hole, 202f, 203, 220-225, 221f-222f, 224f, 226f. *See also* Parallel-hole collimators.  
     penetration of. *See* Septal penetration.  
     pinhole, 202-203, 202f  
     scatter from, 204-205  
     sensitivity of, 223, 224f, 225t, 227, 231  
     septal thickness in, 203, 203f  
     slant-hole, 203  
     for small animal imaging, 207-208  
   compact, 207, 208f  
   components of, 196-206, 196f  
   counting rates for  
     high, 213-216  
     measurement of, 230  
   current availability of, 4  
   definition of, 195  
   derandomizers for, 213-214  
   detectors in, 197-201, 207  
     thickness of  
       detection efficiency and, 211, 212f  
     intrinsic spatial resolution and, 210, 211f  
   development of, 196  
   digital image processing for, 197, 200, 364, 365f, 482.  
     *See also* Digital image processing.  
   dual-headed, 206-207, 206f  
   dynamic imaging with, 197, 206-207  
   edge packing and, 217  
   electronics of, 197-201, 197f, 198f, 199f, 200f, 201f  
   energy corrections and, 217-218  
   energy selection for, 200, 201f  
   energy window for, 212, 212f, 213, 218, 218f, 336, 337  
   event detection in, 204-206, 205f  
   event localization in, 197, 198, 200f, 219  
   film recorders for, 196  
   flood-field images from, 216f, 217  
   gallbladder imaging with, 207f  
   gamma-ray energy in, 211  
   historical development of, 4, 4f, 196  
   image display for, 197  
   image formation in, 196-197  
   imaging modes with, 196-197

Gamma cameras (*Continued*)  
   intrinsic spatial resolution of, 209-211, 210f-211f. *See also* Spatial resolution: intrinsic.  
   Compton scattering and, 209  
   detection efficiency vs., 211, 212f  
   detector thickness and, 210, 211f  
   full width at half maximum and, 210-211, 225  
   gamma ray energy and, 210, 210f  
   improvement of, 219  
   limits on, 209-210  
   measurement of, 210, 229  
   optimum, 210-211  
   mobile, 207, 208f  
   modulation transfer functions for, 237, 238f  
 NaI(Tl) crystal in, 196-198, 196f  
 performance of, 209-231  
   collimators in, 220-223, 221f, 222f, 224f, 225, 225t, 226f, 230  
   dead time in, 213-214, 230  
   detection efficiency in, 211, 212f  
     detector thickness and, 211, 212f  
     nonuniform, 217  
   energy resolution in, 150, 201, 211-213, 212f  
     measurement of, 231  
   at high counting rates, 213-216  
   image nonlinearity in, 216-217, 216f, 218, 218f-219f  
   image nonuniformity in, 217-219, 218f-219f, 243  
   measurements of, 228-231  
   pulse pile-up in, 213-216, 213f, 214f-215f  
   spatial resolution in. *See* Spatial resolution.  
   tuning methods and, 219-220, 220f  
 in PET, 327f, 329-330  
 photomultiplier tubes of, 196, 196f  
   arrangement of, 196-198, 196f, 216  
   charge integration time for, 214  
   dead time and, 214  
   energy resolution and, 149-150  
   image nonlinearity and, 216, 216f  
   image nonuniformity and, 217  
   intrinsic resolution and, 209, 210, 234  
   light sharing between, 198, 199f  
   pulse pile-up and, 214  
   in scintillation event localization, 198-200  
   statistical fluctuations in, 209-210  
   tuning of, 219-220, 220f  
   photopeak selection for, 200, 201f  
   pincushion artifacts and, 199-200, 215f, 216



- Gamma cameras (*Continued*)  
 quality assurance for, 228-231  
 response characteristics of, 254, 254f  
 scintillation event localization in  
   in analog camera, 198-200  
   in digital camera, 200  
 sensitivity of, measurement of, 231  
 single-headed, 206-207, 206f  
 for small animal imaging, 207-208  
 spatial linearity and, measurement of, 229-230  
 in SPECT, 279-280  
 in SPECT/CT, 350f, 351, 352f  
 static imaging with, 197  
 system resolution of, 210-211, 214, 225, 227-228  
   measurement of, 229  
 technical advances in, 207  
 in tomographic imaging, 254, 254f, 255, 255f, 256f  
   for PET, 4, 325-326, 327f, 329-330, 332, 334  
   for SPECT, 279-280, 280f, 281, 283, 301-303  
 triple-headed, 206-207  
 types of, 206-208, 206f, 207f, 208f  
 uniformity measures for, 230  
 whole-body imaging with, 207f  
 X- and Y-position signals in, 199-200
- Gamma probes, intraoperative, 193f, 194
- Gamma rays. *See also* Photons.  
 annihilation, 25  
 biologic effects of, 78, 428  
 in collimators, 201-203  
 Compton scattering of. *See* Compton scattering.  
 detection of. *See* Radiation detectors.  
 in electromagnetic spectrum, 8, 8f  
 energy of  
   attenuation and, 163-164, 164f  
   in SPECT, 287-294  
   gamma camera resolution and, 211-213, 234  
   intrinsic efficiency and, 158, 159f, 174, 175f  
   nuclear transitions and, 15  
   photofraction and, 159, 160f, 174, 174f  
   pulse-height spectrum and, 142-147, 143f, 145f, 146f, 147f, 151  
   scatter and, 163-164, 164f  
   in vivo measurements and, 163  
 interactions with matter, 74-78  
 in nuclear medicine, 1  
 from nuclear transitions, 8-9, 8f, 15  
   in ( $\alpha$ ,  $\gamma$ ) decay, 28  
   in ( $\beta^+$ ,  $\gamma$ ) emission, 26  
   in ( $\beta^-$ ,  $\gamma$ ) emission, 21-22, 22f, 23f  
   in (EC,  $\gamma$ ) decay, 24, 24f  
   isomeric, 22-23, 23f, 24  
   in (n,  $\gamma$ ) reaction, 46
- Gamma rays (*Continued*)  
 penetration by, 195  
   septal, 205, 220-221  
   prompt, 45-46  
   pulse-height spectrum of, 142-147, 143f, 145f, 146f, 147f, 151  
   radiation safety and, 434, 435, 437  
 Gamma-ray converters, 158-159  
 Gamma-ray probes  
   miniature, 192-194, 193f  
   in oncology, 192-193  
   radiation detectors for, 193
- Gas amplification  
 in Geiger-Müller counters, 92-93, 94f  
 in ionization chambers, 91, 92f  
 in proportional counters, 91, 92f
- Gas chromatograph  
 with gas-filled detector, 190  
 with liquid scintillation counter, 188  
 with NaI(Tl) detector, 182, 183f
- Gas flow counters, 190
- Gas flow counting with LS systems, 188
- Gas proportional counters. *See* Proportional counters.
- Gases, radioactive  
 dose limits for, 431-432  
 safe handling of, 437, 438
- Gas-filled detectors, 87-96, 189-190. *See also* Geiger-Müller (GM) counters; Ionization chambers; Proportional counters.  
 advantages and limitations of, 102  
 applications of, 189-190  
 in dose calibrators, 189-190  
 energy deposition in, 141  
 in gas flow counters, 190  
 Geiger-Müller counters, 92-96, 93f-95f  
 intrinsic efficiency of, 158-159  
 ionization chamber, 87-91, 89f-91f. *See also* Ionization chambers.  
 principles and design of, 87, 88f  
 proportional counters, 91-92, 92f  
 semiconductor, 96-97, 97f
- Gated imaging, 369  
 in cardiac studies, 234, 303, 304, 304f, 392, 392f  
 with gamma camera, 197  
 motion blurring and, 245
- Gaussian blurring function, 235-236, 491
- Gaussian distribution, 127f, 128  
 statistical tests and, 133, 135, 138
- Gaussian function, convolution of, 491
- Gaussian response profile of annihilation coincidence detector, 308, 310f
- Gaussian smoothing filters, 373, 375f
- Gaussian spectral curve, 149
- Geiger-Müller (GM) counters,  
 92-96, 93f, 94f, 95f  
 avalanche ionization in, 92-93, 94f  
 backscatter and, 166-167, 167f  
 for  $\beta$ -emitting radionuclides, 167  
   as gas flow counters, 190  
   counting curves for, 94, 95f  
   dead time in, 168, 188  
   intrinsic efficiency of, 158-159  
   limitations of, 93, 95, 166-167  
   pancake, 95-96, 95f  
   power supply for, 122  
   principles and design of, 92, 93f, 95-96, 95f  
   pulse signals of, 107, 107t  
   self-absorption and, 166-167, 167f  
   self-quenched, 93-94  
   as survey meter, 95-96, 95f, 439
- Generators, 24, 50-53, 51f, 51t  
 contaminants in, 50-53, 58  
 fission moly, 53  
 historical development of, 2  
 radionuclide, 50-53, 51f-52f, 51t  
 safe handling of, 436
- Geometric detection efficiency. *See* Detection efficiency: geometric.
- Geometric mean, in conjugate counting, 287-293  
 correction for, 293-294, 294f
- Germanium-68, 165t  
 characteristics of, 457  
 as rod source, in PET scanner, 328f, 329, 338
- Germanium detectors, 89t, 96-97. *See also* Radiation detectors; Semiconductor detectors.  
 detection efficiency of, 158  
 intrinsic, 96, 158  
 lithium-drifted, 89t, 96-97, 97f  
 spectrometry with, 151, 152f
- GFR. *See* Glomerular filtration rates (GFR).
- Gibbs phenomenon, 486
- Glass, leaded, 436-437, 436f
- Glass vials for liquid scintillation counting, 184-185
- Glomerular filtration rate (GFR), 379
- Glucose. *See also* Fluorodeoxyglucose (FDG).  
 metabolism of, 396-401  
 FDG model of, 397-401, 398f  
 Michaelis-Menten hypothesis and, 396-397, 397f  
 parametric brain imaging and, 400, 401f  
 Sokoloff deoxyglucose method and, 397, 400  
 transport of, 389
- GM counters. *See* Geiger-Müller (GM) counters.
- Graphics processing units, 363
- Gray (Gy), 89, 407, 433-434
- Grayscale images, 367, 370f

Ground state of nucleus, 14, 15, 15f, 16  
 GSO. *See* Gadolinium oxyorthosilicate (GSO).

## H

Half-life, 33-34  
   biologic, 59, 410-411, 411f, 412  
   effective, 411-412  
   physical, 33-34  
     average lifetime and, 34  
     for clinical applications, 59, 60-61  
     cumulated activity and, 410-412  
   of radiopharmaceuticals, 59  
 Half-time of turnover, 384, 480  
 Half-time of uptake, 410  
 Half-value layer (HVL). *See* Half-value thickness (HVT).  
 Half-value thickness (HVT), 82, 82t, 83, 84  
 Hann filter, 261, 262f  
 Harper, Paul, 2-4  
 Hasegawa, Bruce, 350  
 Health care workers, occupational exposure of. *See* Radiation safety.  
 Health physics, 427-428. *See also* Radiation safety.  
   air kerma and, 428-431, 434-435  
   dose-modifying factors and, 428  
   exposure rate and, 89, 428-431  
   quantities and units in, 428-431, 429t  
 Heart. *See* Cardiac studies;  
   Organs.  
 Heat scale, 367  
 Hevesy, Georg de, 2  
 Hexokinase, 396, 397, 398f, 399  
 HIDA, <sup>99m</sup>Tc-labeled, 60t, 207f  
 High-voltage power supplies, 122  
 HMPAO  
   (hexamethylpropyleneamine oxime), 304, 304f  
 Hormesis, 427  
 Hot lesions, 246  
 Hot-body scale, 367  
 Hounsfield units, 349  
 HPGe (high purity germanium), 97  
 Human observer performance studies, 233  
   contrast-detail studies, 247-248, 248f-249f  
   receiver operating characteristic studies, 248-251, 250f  
 HVT. *See* Half-value thickness (HVT).  
 Hybrid imaging systems  
   CT-based, 346-354, 356-360. *See also* PET/CT; SPECT/CT;  
     X-ray computed tomography.  
   advantages of, 332-334  
   future directions for, 345-346  
   image co-registration and, 376  
   MRI-based, 360-361  
 Hydrogen-3 (tritium), 449. *See also* Liquid scintillation counters (LSCs).  
 Hypoxia, tracers for, 381t

Image quality (*Continued*)  
   in iterative reconstruction, 273  
   Nyquist frequency and, 263  
   sampling and, 263-265  
   spatial resolution and, 233-239.  
     *See also* Spatial resolution.  
   in SPECT, 302-303  
   system resolution and, 265-266  
   tomographic reconstruction and with FT and FBP, 263, 264f, 265-270, 265f, 266f, 267f  
   with iterative methods, 275-276  
   in x-ray computed tomography, 263-270  
 Image reconstruction. *See* Reconstruction tomography.  
 Image registration. *See* Co-registration.  
 Image segmentation, 375, 377f  
   in CT-based attenuation correction, 357  
 Image smoothing, 373, 375f, 489  
 Image space, 258  
 Image visualization, 369-372, 370f-372f  
 Image-frame decay corrections, 35-36, 36f  
 Images. *See* Digital images.  
 Imaging, radionuclide. *See* Gamma cameras; Tomographic imaging.  
 Impedance matching, 107  
 Impulse response, 391-392  
 In vitro counting systems, 173  
 In vivo counting systems, 173, 192-194, 192f, 193f  
   detection efficiency in, 156, 166  
 Index of refraction of scintillators, 101t, 104  
 Indium-111, 58t  
   characteristics of, 463  
   pentetretotide labeled with, 305  
   in radioimmunoguided surgery, 193  
   white blood cells labeled with, 5t  
 Infection, tracers for, 5t, 381t  
 Information density, 244, 245, 247, 247f  
 Inorganic scintillators, 100-103, 101f, 101t, 102f, 103f  
   NaI(Tl), 100-103, 101f-103f, 101t. *See also* NaI(Tl) detectors.  
   for PET, 316, 322t, 324, 326  
   properties of, 101t, 103, 103f  
   selection of, 103  
 In-plane resolution, 301  
 Input function, 390, 391, 391f  
 Instrumentation. *See* Counting systems; Electronic instrumentation; Radiation detectors.  
 Integral uniformity, for gamma cameras, 229-230  
 Integration circuits, 111, 112f  
 Integration time  
   energy resolution and, 150  
   in gamma camera, 214  
 Internal conversion, 15, 22-23, 23f

- Internal dosimetry. *See* Radiation dosimetry, internal.
- Internal standardization method, 186, 186f
- International Commission on Radiological Protection (ICRP), 417, 431, 433, 434t. *See also* Radiation safety.
- International Commission on Radiological Units (ICRU), 437
- Intersubject image co-registration, 375-376
- Intrasubject intramodality image co-registration, 375-376
- Intrinsic detection efficiency. *See* Detection efficiency: intrinsic.
- Intrinsic germanium detectors, 96
- Intrinsic photopeak efficiency for NaI(Tl) well counters, 174, 176f
- of semiconductor detector, 191
- Intrinsic spatial resolution. *See* Spatial resolution: intrinsic.
- Intrinsic uniformity, 229-230
- Inverse  $\beta^-$  decay, 24-25
- Inverse Fourier transform, 258
- Inverse-square law, 156, 157f, 435
- Iodine-123, 464-465
- Iodine-124, 466-467
- Iodine-125, 24-25, 24f, 58t, 468-469
- Iodine-129, as calibration standard, 165t
- Iodine-131
- characteristics of, 470-471
- dosimetry of, internal, 416, 420t
- as iodide ion, 57
- mean dose per cumulated activity of, 415-416, 420t-421t
- mock calibration source for, 177
- notation for, 14
- properties of, 58t
- in radioimmunoguided surgery, 193
- safe handling of, 432
- in thyroid imaging, 2, 3f, 5t
- Iodine escape peak, 144, 144f
- Ionization, 87, 87f
- avalanche
- in Geiger-Müller counters, 92-93, 94f
- in ionization chambers, 91, 92f
- in proportional counters, 91, 92f
- Bragg peak in, 68, 69f
- collisional energy losses in, 64-65, 66f-67f
- pair production and, 76-77, 87. *See also* Pair production.
- radiation detection and, 87, 141-142, 142f
- secondary, 63, 64f
- to charged-particle interactions, 63, 64, 141-142, 142f
- to photon interactions, 74, 76-77, 78, 141, 142f
- specific, 68, 69f, 71
- Ionization (*Continued*)
- tracks associated with, 66, 67, 67f, 68, 70
- units of radiation and, 428-429
- Ionization chambers, 87-91, 88f, 89f, 90f, 91f
- detector materials for, 89t
- in dose calibrators, 89, 89f, 189-190
- efficiency of, 90-91, 158-159
- energy response curve for, 90-91, 91f
- gas amplification in, 91, 92f
- gas-filled, 87-96
- limitations of, 90-91
- in pocket dosimeters, 89-90, 90f
- principles and design of, 87-91, 88f
- in survey meters, 89, 89f
- voltage response curve for, 87-88, 88f, 91, 92f
- vs. proportional counters, 91-92
- Ionization detectors, 87. *See also* Gas-filled detectors; Semiconductor detectors.
- gas-filled, 87, 88f
- semiconductor, 96-97, 97f
- Ionization events
- primary, 141, 142f
- secondary, 141, 142f
- Ionization potential, 68
- Ionizing radiation, 63
- biologic effects of, 427-428
- definition of, 8, 63
- secondary, 74
- Isobaric decay modes, 20, 24, 25-26, 27
- Isobars, 14, 14f
- stability of, 17
- Isomeric state, 14-15
- decay of, 19-20
- Isomeric transition, 22
- Isomers, 14
- Isotones, 14, 14f, 16f, 17, 28
- Isotope effect, 20, 380
- Isotopes, 14, 14f
- on chart of nuclides, 28
- definition of, 14
- radioactive. *See* Radionuclides.
- stable, 16f, 17
- Isotropic emission, 156
- Iterative reconstruction, 262, 270-273
- for coded aperture imaging, 285
- cone-beam data in, 275
- 3-D, 276
- expectation-maximization, 272-273
- filtered backprojection vs., 271-272
- forward projection and, 270-272
- image quality in, 273
- overview of, 258
- for PET data, 331, 332, 334
- sampling in, 273
- scatter corrections in, 298, 299
- steps in, 270-271, 270f-271f
- tissue attenuation information in, 296, 298
- J**
- Joule, 407
- K**
- K absorption edges, 79, 80f
- K shells, 65f-67f, 67-70, 73t
- Kerma, air, 89, 428-431, 429t
- Kety-Schmidt method, 387, 395 keV. *See* Kiloelectron volt (keV).
- Kidney, functional evaluation of, 379
- Kilocurie, 32
- Kiloelectron volt (keV), 8
- Kinetic energy
- kerma and, 429, 429t
- in radioactive decay, 19, 20
- Kinetic modeling. *See* Tracer kinetic modeling.
- k-space, 258-259, 260f, 481, 482, 483, 483f, 484, 485f, 487
- Nyquist frequency and, 263, 484, 485f, 487
- Kuhl, D.E., 4
- L**
- L (linear energy transfer), 68
- L shells, 65f, 67-70, 72f-73f, 73t
- Labeled microsphere technique, 393-394
- Labels/labeling. *See also* Radiopharmaceuticals.
- by analog creation, 60
- by direct substitution, 59-60
- with  $^{99m}\text{Tc}$ , 60, 60t
- with positron emitters, 60-61
- of radiopharmaceuticals, 59-60
- requirements for, 381-382
- Laboratory design, 438
- Laboratory monitors, 436
- L absorption edges, 79, 80f
- Lanthanum bromide, 101t, 103
- Lanthanum chloride, 103
- Laplacian technique, 373, 375, 376f
- Lawrence, Ernest O., 2, 3f
- LC. *See* Lumped constant (LC).
- LCD. *See* Liquid crystal display (LCD).
- Lead
- in bar phantom, 235
- in collimator
- of gamma camera, 195, 196, 203, 221
- of SPECT system, 281, 283
- mass attenuation coefficients of, 476-477
- Lead shielding, 436-437, 436f. *See also* Shielding.
- for dose calibrator, 189, 437
- natural radioactivity in, 178
- in PET systems, 323
- for well counter, 178, 180f, 181, 183f
- x-ray peaks from, 144, 151
- Lead x-ray peaks, 144
- Leaded glass, 436-437, 436f
- Leading-edge timing, 115, 115f
- LEDs. *See* Light-emitting diodes (LEDs).

- Left ventricular ejection fraction, 392, 392f
- Lesion detectability. *See* Detectability.
- Lesions. *See* Detectability.
- LET. *See* Linear energy transfer (LET).
- Licensing for use of radionuclides, 431, 432, 433
- Ligand, 60
- Light coupling. *See* Optical coupling.
- Light guide of gamma camera, 196, 196f, 198, 219
- Light-emitting diodes (LEDs), 219
- Limited-angle tomography, 266
- Limited-scope licenses, 431
- Line broadening, 148. *See also* Energy resolution.
- Line integrals, 254, 254f
- Line of response, 254, 254f  
actual vs. idealized, 285-286  
conjugate counting and, 287  
scattering into, 296  
in transmission scan, 295-296
- Line of stability, 16, 16f  
decay modes and, 28
- Linear accelerators, 47
- Linear attenuation coefficients, 78, 81, 82, 83, 158  
of bone, 287, 294, 338  
coincidence rate and, 319  
of collimator material, 221, 222  
detection efficiency and, 158, 159  
in PET, 321  
of tissue, 192, 296  
transmission scan and, 294, 338
- Linear energy transfer (LET)  
of charged particles, 68, 71  
of photons, 78
- Linear nonthreshold (LNT) model, 427
- Linear regression, 139-140
- Linear sampling distance, 263, 265  
in annihilation coincidence detection, 318, 318f  
in imaging processing, 365-366  
with iterative algorithms, 273  
performance measurement and, 301  
pixel size and, 366  
SNR and, 267
- Linear stopping power, 68
- Line-spread function (LSF)  
distance from source vs., 288f  
FWHM and, 235  
of gamma-camera collimators, 222-223, 222f, 224f, 225  
modular transfer function and, 238, 240-241, 242f  
pixel size and, 366  
in resolution evaluation, 235  
scattered radiation and, 240-241, 242f  
septal penetration and, 240-241, 242f  
in SPECT imaging, 288f, 298
- Liquid chromatography, with NaI(Tl) detectors, 182, 183f
- Liquid crystal display (LCD), 124, 367
- Liquid nitrogen in semiconductor detectors, 97, 97f
- Liquid scintillation (LS), 104-106, 105f, 187-188
- Liquid scintillation (LS) cocktails, 105, 187
- Liquid scintillation counters (LSCs), 184-185  
applications of, 105, 183-184, 189  
automated multi-sample, 188-189, 188f  
calibration of, 185  
Cerenkov counting with, 188  
coincidence detection by, 184  
components of, 105f, 182-184, 183f  
dark adaptation of samples and, 185  
dead time in, 168  
efficiency of, 157, 185  
flow counting with, 188  
gas/liquid chromatography with, 188  
limitations of, 106  
mixtures of radionuclides in, 185, 188-189  
noise in, 184, 185, 186  
organic scintillators for, 104-106  
principles and design of, 182-184, 183f  
pulse signals of, 108t  
pulse-height spectrometry with, 141, 153, 153f, 184, 185f  
quenching in, 106, 188  
correction methods for, 185-187, 186f-187f  
radionuclides counted with, 105, 166, 182-184, 183t  
refrigeration of, 184  
sample preparation for, 106, 187-188  
scintillator solutions in, 104-106, 187  
vials for, 184-185
- List-mode acquisition, 335, 368-369
- Lithium fluoride, thermoluminescent, 440f
- Logarithmic rate meters, 121, 121f
- Logic pulses, 118-119
- Lower-level discriminator, 113, 114f
- LS. *See* Liquid scintillation (LS).
- LSCs. *See* Liquid scintillation counters (LSCs).
- LSF. *See* Line-spread function (LSF).
- LuAP, 101t, 103
- Lumped constant (LC), 399, 400
- Lung perfusion, 393
- Lung ventilation, 381t
- Lutetium oxyorthosilicate (LSO), 101t, 102-103  
in PET systems, 321, 322t, 324, 325, 325f, 326  
energy resolution and, 337
- Lutetium yttrium orthosilicate (LYSO), 101t, 102-103
- Lymph nodes, sentinel, gamma-ray probes for, 192-193
- M**
- MAG3 (mercapto-acetyl-triglycine), 5t
- Magnetic resonance imaging (MRI)  
combined with nuclear medicine imaging, 376, 377f  
image reconstruction in, 4, 259  
in k-space, 259  
limitations of, 1  
with PET, 345-346, 360-361, 361f  
with SPECT, 360  
stray fields from, gamma camera and, 197
- Malignant melanoma, sentinel nodes in, gamma-ray probes for, 193-193
- Mass  
equivalence to energy, 8, 15-16, 19  
units of, 7-8
- Mass attenuation coefficients, 79, 158  
absorbed dose and, 430  
table of, 476-477
- Mass deficiency, 15
- Mass number (A), 13
- Mass-energy conversion in radioactive decay, 19
- Matrix of pixels, 365, 365f
- Matrix size, 365-366, 366f
- Maximum intensity projection, 369-371
- Maximum-likelihood (ML) reconstruction, 272-273
- MCAs. *See* Multichannel analyzers (MCAs).
- MDA. *See* Minimum detectable activity (MDA).
- MDP. *See* Methylene diphosphonate (MDP).
- Mean dose per cumulated activity, 411f, 414f, 415-416, 418t-419t  
for  $^{18}\text{F}$ , 415-416, 422t-423t  
for  $^{131}\text{I}$ , 415-416, 420t-421t  
for  $^{99\text{m}}\text{Tc}$ , 415-416, 418t-419t
- Mean free path, photon, 82, 82t
- Mean transit time, 380, 380f, 384
- Mean value, 126, 127  
arithmetic vs. geometric, 287-288, 288f  
confidence interval for, 127, 127t  
*t*-test and, 135-137  
uncertainty in, 128
- Measurement errors, 125-126  
blunders, 125  
propagation of, 128-130  
random, 125-126  
systematic, 125  
types of, 125-126
- Measurement standards, 125



- Measurements. *See also* Statistical analysis.  
 constant multipliers and, 129  
 frequency distribution of, 126, 127f  
 inaccurate, 125  
 reproducible, 126  
 sums and differences of, 129  
 true value of, 126  
 uncertainty in, 126-127, 129
- Medical Internal Radiation Dose (MIRD) Committee, 28, 407, 414
- Medical Internal Radiation Dosimetry (MIRD) method. *See* Absorbed fraction (MIRD) method.
- Medical Internal Radiation Dosimetry (MIRD) publications, 28
- Megaelectron volt (MeV), 8
- Melanoma, sentinel nodes in, gamma-ray probes for, 192-193
- Metabolic tracers. *See* Fluorodeoxyglucose (FDG); Methylene diphosphonate (MDP); Oxygen-15.
- Metastable radionuclides, generators of, 24, 50-53, 51t, 52f
- Metastable state, 10f, 14-15  
 decay of, 22
- Methylene diphosphonate (MDP), 5t, 60t, 207f, 479
- Metric units, 7
- MeV. *See* Megaelectron volt (MeV).
- Michaelis-Menten kinetics, 396-397, 397f
- Microcurie, 32
- Microdosimetry, 425
- Microprocessors, 363
- Microsphere technique, 393
- Millibarn, 53-54
- Miniature probes for surgery, 192-194
- Minimum detectable activity (MDA), 131  
 with semiconductor detectors, 191
- MIRD Committee. *See* Medical Internal Radiation Dose (MIRD) Committee.
- MIRD method. *See* Absorbed fraction (MIRD) method; Radiation dosimetry, internal.
- MIRD publications. *See* Medical Internal Radiation Dosimetry (MIRD) publications.
- ML reconstruction. *See* Maximum-likelihood (ML) reconstruction.
- ML-EM method, 272-273
- Mn-54, 165t
- Mock calibration sources, 177
- Modulation transfer function (MTF), 236-237, 487, 492  
 3-D representation of, 238  
 derivation of, 238  
 line-spread function and, 238, 240-241, 242f  
 scatter and, 241, 242f
- Modulation transfer function (MTF) (Continued)  
 of SPECT system, 301  
 system effects and, 238
- Moly shield, 53
- Molybdenum-99, 45, 51f, 51t, 53  
 breakthrough of, 50-53, 84  
 characteristics of, 460  
 detection of, with dose calibrator, 189  
 production of, 44-45
- Molybdenum-99—technetium-99 generators, 50-53, 51f, 51t, 60
- Monitoring of radiation. *See* Radiation monitoring; Radiation safety; Survey meters.
- Motion, patient, 234, 234f  
 attenuation correction artifacts and, 359  
 breath-holding and, 359  
 gated imaging and, 234, 368  
 in SPECT, 303, 304f  
 image quality and, 234, 266, 359  
 in PET, 308, 339
- Motion blurring, 234, 266  
 attenuation correction artifacts and, 359  
 breath-holding and, 359  
 image quality and, 234, 266, 359
- MRI. *See* Magnetic resonance imaging (MRI).
- MTF. *See* Modulation transfer function (MTF).
- Multichannel analyzers (MCAs), 113, 116-118, 116f  
 dead time of, 168  
 of liquid scintillation counters, 184  
 of NaI(Tl) well counters, 173, 180f, 181  
 for radiochemical identification, 182  
 of semiconductor detectors, 190
- Multi-pinhole collimators, 202f, 203
- Multiple scattering, intrinsic resolution and, 209, 210
- Multiprobe systems, 192
- Multi-slice imaging, 262-263
- Mu-metal shielding, 99, 101f
- Muscle, *f* factor for, 430, 430f
- Myocardial imaging  
 with <sup>99m</sup>Tc-labeled red cells, 392, 392f  
 SPECT in, 281-283, 303, 305f, 306
- Myocardial perfusion. *See* Cardiac studies.
- N**  
 (n,  $\gamma$ ) reaction, 45, 46  
 (n, p) reaction, 46, 47
- NaI(Tl) detectors, 100-103, 182  
 advantages of, 102, 190-191  
 amplifiers for, 113  
 for cardiac SPECT, 281-283
- NaI(Tl) detectors (Continued)  
 counting applications of  
 with gas/liquid chromatographs, 179  
 with large sample volumes, 182  
 with NaI(Tl) well counters, 173, 174f, 174t  
 cracked crystal in, 104, 150, 217  
 dead times of systems with, 179  
 detection efficiency of, 157, 174, 175, 175f-176f, 179  
 intrinsic, 158-159  
 with source in tissue, 163, 164f  
 total, 160-161, 161f  
 digitization of signals from, 117-118  
 disadvantages of, 102  
 energy linearity and, 147-148  
 energy resolution and, 148-151  
 in gamma cameras, 196-198, 196f  
 crystal thickness in, 210, 210f, 211, 211f  
 limitations of, 216  
 limitations of, 182  
 linear attenuation coefficient of, 321, 322t  
 mass attenuation coefficients of, 476-477  
 minimum detectable activity  
 with, 191  
 in PET scanners, 321, 322t, 324, 327f, 330, 337  
 photofraction with, 159, 160f  
 power supply for, 122  
 preamplifiers for, 108-109  
 principles and design of, 91, 100-102, 101f  
 pulse-height spectrometry with, 142-151. *See also* Pulse-height spectrometry: with NaI(Tl) detectors.  
 advantages of, 151  
 calibration for, 147-148  
 counting rate and, 146, 147f  
 crystal size and, 145-146, 146f, 158, 159, 160f  
 energy linearity in, 148-149, 148f  
 energy resolution in, 148-151, 149f, 150f  
 vs. semiconductor detectors, 151, 152, 152f  
 gamma-ray energy and, 147, 147f  
 scatter rejection in, 240  
 spectral structure in, 142-145, 143f, 144f, 145f, 146f  
 timing methods in, 114-115  
 in SPECT  
 in brain imaging, 280-281, 282f  
 in cardiac imaging, 281-283  
 in CERASPECT system, 281, 282f  
 in small-animal imaging, 281-283, 282f  
 in SPRINT II system, 280-281, 282f  
 through-hole, 180, 180f-181f  
 timing methods for, 114-116

NaI(Tl) detectors (*Continued*)  
 in whole-body counters, 194  
 window fractions and, 170-171  
 in well counters. *See* NaI(Tl) well counters.

NaI(Tl) probe systems, 207, 208f

NaI(Tl) well counters, 173-182  
 absolute activity assays and, 177  
 applications of, 182  
 automated multiple-sample, 179-182, 180f  
 background in, 179, 180, 181  
 background radiation and, 177-178, 179, 180, 181  
 calibration of, 178  
 coincidence detection and, 163  
 coincidence summing in, 145, 146f, 163  
 dead time of, 179, 182  
 detection efficiency of, 157, 174, 175, 175f-176f, 179  
 detector characteristics in, 173, 174f  
 detectors in, 173, 174f, 174t  
 through-hole, 180, 180f  
 efficiency of, 174, 175, 175f-176f, 179  
 geometric, 157  
 energy calibration of, 178  
 energy resolution of, 173  
 multichannel analyzers for, 173, 180f, 181  
 multiple radionuclides in, 178-179, 178f, 181, 182  
 rod standards for, 164, 165f  
 sample volume effects and, 175-177, 177f  
 shielding for, 177-178  
 volume effects in, 174, 175-177, 177f  
 with through-hole detector, 180, 180f-181f

Nanocurie, 32

Narrow-beam attenuation  
 coefficient, 297

Narrow-beam geometry, 79-83, 81f, 82t

National Council on Radiation Protection and Measurement (NCRP), 431, 433, 434t

NCRP. *See* National Council on Radiation Protection and Measurement (NCRP).

Negative-ion cyclotrons, 48-49, 49f

Net extraction fraction, 387

Neurodegenerative diseases, 341-342

Neutrinos, 20-21, 24, 25

Neutron activation, 45-47, 46t

Neutron activation analysis, 190, 192

Neutron deficient nuclides, 17, 28

Neutron number, 13

Neutron-capture cross-sections, 54

Neutrons, 13-14, 13t  
 arrangement of, 14-15  
 decay modes involving. *See also specific modes.*  
 $\beta^-$  decay as, 20-21  
 electron capture as, 24, 28

Neutrons (*Continued*)  
 fission as, 26  
 positron emission and, 25  
 energy levels of, 10f, 14-15  
 equivalent dose of, 408t  
 fission, 28, 43  
 forces on, 14-15  
 nuclear stability and, 14-18, 16f-17f  
 number of, 13-14  
 properties of, 13, 14t  
 in shell model, 14  
 slow (thermal), 43-44

Neutron-to-proton ratio, 16

NIM. *See* Nuclear instrument modules (NIM).

Nitrogen-13, 58t, 60-61, 382, 450

Noise, 233, 239-240, 243-247  
 contrast-to-noise ratio and, 243-244  
 in reconstruction tomography, 266-268  
 definition of, 233  
 in filtered backprojection, 260-263, 293f  
 image quality and, 233, 243-247  
 image smoothing and, 373, 375f  
 in iterative reconstruction, 273  
 in liquid scintillation counters, 184  
 random, 243  
 contrast-to-noise ratio and, 243-244  
 in reconstruction tomography, 266-268  
 reduction of, by coincidence detection, 184  
 sampling requirements and, 366  
 signal-to-noise ratio and, 110  
 in filtered backprojection, 260-261, 263, 264f  
 image smoothing and, 373, 375f  
 in reconstruction tomography, 266-268  
 spectral blurring and, 148  
 structured, 243

Noise equivalent counting rates, 340-341, 341f

Noncolinearity, 314, 315f, 316

Nondisplaceable compartments, 384, 402f

Nonlinear energy response of NaI(Tl) detectors, 148, 149-150, 178

Nonparalyzable counting systems, 168-169, 168f-169f

Normal distribution, 127f, 128, 133

NRC. *See* Nuclear Regulatory Commission (NRC).

Nuclear atom, 9

Nuclear binding energy, 15-16  
 nuclide stability and, 17-18, 17f

Nuclear chain reactions, 43. *See also* Fission.

Nuclear counting statistics, 125-140. *See also* Measurements; Statistical analysis.

Nuclear counting systems,  
 comparison of, 132

Nuclear emissions, 15. *See also* Radioactive decay.

Nuclear energy-level diagrams, 15, 15f

Nuclear families, 14, 14f

Nuclear fission, 26, 28  
 radioactive decay by, 28  
 radionuclide production by, 43-47  
 in reactors, 43-44

Nuclear forces, 14-15

Nuclear fragments, 43

Nuclear instrument modules (NIM), 122-123

Nuclear medicine, 1-6  
 advantages of, 1-2  
 applications of, 1-2, 12t  
 current practice of, 4-5  
 fundamental concepts of, 1  
 historical perspective on, 2-4, 3f-4f  
 risks of procedures in, 424, 427  
 role of physics in, 6  
 safety of, 2  
 selected procedures in, 5t

Nuclear physics  
 basic concepts of, 7-18  
 in medicine, 6

Nuclear reactors, 43-44, 44f  
 neutron-capture cross sections in, 54  
 principles and design of, 43-44, 44f  
 radionuclide production in, 43-47, 46t

Nuclear Regulatory Commission (NRC), 431, 432, 433

Nuclear-binding energy, 15-18  
 per nucleon, 17, 17f

Nucleons, 13-14, 13t. *See also* Neutrons; Protons.  
 arrangement of, 14-15  
 basic properties of, 13t  
 binding energy per, 17, 17f  
 energy levels of, 10f, 14-15  
 forces on, 14-15  
 nuclear stability and, 14-18, 16f-17f  
 in shell model, 14

Nucleus, 9, 13-18. *See also* Atomic number (Z).  
 binding energy of, 15-16, 17-18, 17f  
 composition of, 13, 13t  
 daughter, 19  
 decay of. *See* Radioactive decay.  
 in excitable state, 10f, 14-15  
 excited states of, 14, 15, 21, 22, 22f, 24, 25  
 forces and energy levels in, 14-15, 15f  
 in ground state, 14  
 mass number of, 13  
 in metastable state, 10f, 14-15  
 metastable states of, 14-15, 22, 24  
 neutron number of, 13  
 notation for, 13-15, 14f  
 parent, 19  
 of Rutherford atomic model, 9

- Nucleus (*Continued*)  
 shell model of, 14  
 stability of, 14-18, 16f-17f  
 radioactive decay and, 19
- Nuclides, 14, 14f. *See also*  
 Radionuclides.  
 chart of, 29f  
 definition of, 14  
 energy-level diagram for, 15, 15f  
 isomers of, 14-15  
 metastable, separation of, 24  
 stable, 14-18, 16f-17f, 27, 28
- Nutt, Ron, 354
- Nyquist frequency, 263, 484, 485f, 487
- O**
- Object detectability. *See*  
 Detectability.
- Object scatter, 144-145, 205  
 with gamma camera, 205, 205f  
 with NaI(Tl) detector, 144, 145, 147, 147f, 152f
- Object space, 258, 481, 483, 483f, 485, 485f, 487
- Observer performance studies, 247-251  
 computer, 233  
 human, 233  
 contrast-detail studies, 247-248, 248f-249f  
 receiver operating characteristic studies, 248-251, 250f
- Occupational dose limits, 432, 434t
- Occupational exposure. *See also*  
 Radiation safety.  
 definition of, 431  
 dose limits for, 431-432, 434t  
 in pregnancy, 433
- Oncology  
 FDG-PET in, 341  
 gamma-ray probes in, 192-193  
 PET/CT in, 355-356, 356f  
 SPECT in, 305-306
- 1/r blurring, 258, 260-261
- One-sided *t* test, 136, 137
- Optical coupling, 149, 150, 151
- Optical windows, 101-102
- Orbits, electron, 9, 10f
- Order of reaction, 385
- Ordered subsets, 272
- Organic scintillators, 104-106  
 in liquid solution, 97, 104-106, 106f, 185, 187, 188  
 plastic, 105, 105f  
 solid, for flow counter, 187
- Organs. *See also* Radiation dosimetry, internal; Tissue. dose estimates for  
 with FDG, 424, 425t  
 phantom models and, 414, 414f, 415  
 for selected radiopharmaceuticals, 478-479t  
 dose limits for, 432, 432t  
 radiation damage to, 427, 428
- Organs (*Continued*)  
 source and target, 408, 413-414, 415, 416, 418t-424t  
 weighting factors for, 424, 428, 429t, 435
- Oscilloscopes  
 analog, 124  
 cathode ray tubes for, 123-124, 123f  
 digital, 124
- Outliers, 138, 138t, 139f
- Oxygen-15, 60-61  
 blood flow measurement with, 393, 395  
 decay of, 25-26, 26f  
 in PET  
 for cerebral perfusion studies, 371, 372f  
 dead time losses with, 339  
 positron range of, 113t, 314, 314f  
 production of, 49  
 properties of, 58, 58t, 381t, 382, 450
- Oxygen utilization rate, 387
- P**
- (p, n) reaction, 47, 50t
- P* value, 134, 134f, 135, 136-137, 136f, 172
- PACs. *See* Picture archival communications systems (PACs).
- Pair production, 76-77, 77f, 78t  
 photon attenuation and, 79, 80f-81f  
 in radiation detectors, 141-142, 142f
- Paired data, 135, 137
- Pancake Geiger-Müller counters, 95-96, 95f
- Parallel-hole collimators, 202f, 203, 220  
 collimator resolution and, 222, 222f, 225t  
 efficiency and, 223  
 FWHM and, 222, 222f, 227  
 hole geometry and, 222  
 source-to-collimator distance and, 223, 224f, 228, 228f  
 system resolution and, 225  
 design and performance of, 220-223, 221f, 222f, 224f, 225, 225t, 226f  
 efficiency of, 222, 224f, 225t  
 collimator resolution and, 223  
 hole geometry and, 222  
 septal thickness and, 223  
 gamma-ray energy and, 221-222, 225t  
 hole geometry in, 222, 222f, 224f  
 line-spread function for, 222-223, 222f, 224f, 225  
 modulation transfer functions for, 237, 238f  
 point-spread function for, 222-223, 222f, 224f, 225  
 in reconstruction tomography, 273
- Parallel-hole collimators (*Continued*)  
 septal thickness in, 203, 203f, 211, 220f-221f  
 efficiency and, 223  
 system resolution of, 225, 227  
 in tomographic imaging, 254-256, 254f, 255f, 256f  
 with SPECT, 279-281, 285, 288, 288f, 291, 293, 294
- Paralyzable counting systems, 168-169, 168f-169f  
 gamma camera as, 213, 230
- Parametric imaging, 372  
 of glucose metabolism in brain, 400, 401f
- Parent nucleus, 19
- Parent-daughter decay, 39-42  
 activity relationships in, 39-42, 39f, 40f, 41f, 42f  
 Bateman equations for, 39-40, 39f  
 definition of, 19  
 in generator, 50, 51, 51t, 52  
 in no equilibrium, 42  
 product activity and, 56  
 in secular equilibrium, 40-41, 40f  
 in transient equilibrium, 41-42
- Partial-volume effects  
 in PET, 340, 373  
 in SPECT, 299, 300f, 373
- Particulate radiation, 8. *See also*  
 Charged particles.
- Partition coefficient, 383, 383f, 395, 396, 399
- Passive transport, 389-390  
 carrier-mediated diffusion and, 389
- Patient motion  
 attenuation correction artifacts and, 359  
 breath-holding and, 359  
 image quality and, 234, 266, 359
- Pauli Exclusion Principle, 9
- Peak detection timing, 115-116
- Penetrating radiation, 82-83. *See also*  
 Photons.  
 absorbed fraction for, 414  
 definition of, 83  
 GM counters for, 95
- Penetration, septal, 205, 220-221
- Pentetreotide, <sup>111</sup>In-labeled, 305
- Percentage uncertainty, 127, 129  
 in counting rate, 130, 131, 132, 133
- Performance studies  
 computer, 233  
 human, 233, 247-251
- Perfusion. *See also* Blood flow. definition of, 386  
 measurement of, 393, 394, 395  
 uptake and, 387
- Periodic table, 9
- Permeability, membrane  
 diffusion constant and, 389  
 extraction and, 387, 387f, 389, 389f
- Persistence time of phosphor in CRT, 124

- Personal computers, 363  
MCA boards for, 117
- Personnel dosimeters, 440-441, 440f  
badge, 440-441, 440f  
pocket, 89-90, 90f, 440-441  
ring, 440-441, 440f
- Pertechnetate,  $^{99m}\text{Tc}$ -labeled, 4f, 51, 60, 480
- PET. *See* Positron emission tomography (PET).
- PET/CT, 4-5, 330, 354-356  
advantages of, 332-334, 356-357  
applications of  
clinical, 355-356, 356f  
small-animal, 356, 356f  
attenuation correction in, 348, 356-360  
image segmentation in, 357  
scanners in  
clinical, 354-356, 354f-355f  
small animal, 356, 356f  
scatter correction in, 337, 356-360
- PET/MRI, 345-346, 360-361, 361f
- Phantoms  
for absorbed fraction method, 409, 414, 414f, 415t  
bar, 235, 235f  
modular transfer functions and, 237-238  
computer-simulation, 258f, 263, 264f, 265, 265f, 266f, 267f  
in contrast-detail studies, 247-248, 248f, 249f  
Cristy-Eckerman, 414, 414f, 415t  
dosimetry calculations based on, 414, 414f, 415, 415t  
in ROC studies, 248  
Rollo, 247-248, 248f  
scatter correction based on, 298  
spatial resolution and, 234-235, 234f-235f  
with bar phantom, 235, 235f, 237-238  
detection efficiency in, 166  
SPECT images of, 289-290, 291, 298, 298f, 299  
volume sensitivity measurement with, 301-302
- PHAs. *See* Pulse-height analyzers (PHAs).
- Phelps, M.E., 4
- Phosphorescence of scintillator solution, 184, 185
- Phosphorus-32, 58t, 452
- Phoswich detectors, 326, 327f
- Photocathodes, 98-99, 98f  
temperature and, 184
- Photodiodes, silicon, 99-100  
avalanche, 100  
in PET systems, 332  
in compact gamma camera, 207  
in intraoperative gamma probe, 193, 193f
- Photoelectric effect, 74, 74f, 77-78, 78t  
in lead shielding, 144  
in photomultiplier tube, 98, 98f, 148
- Photoelectric effect (*Continued*)  
in radiation detectors, 141-142, 142f  
gamma-ray energy and, 147  
iodine escape peak and, 144  
nonlinearity and, 148  
photon attenuation and, 79, 80f-81f  
in scintillation detectors, 102, 103
- Photoelectrons, 74  
in photomultiplier tubes, 98, 100f  
energy resolution and, 149-150
- Photoemissive substance, 98
- Photofraction  
definition of, 159  
for NaI(Tl) detectors, 159, 160f  
in NaI(Tl) well counters, 174, 175f
- Photomultiplier (PM) tubes, 98-99, 98f, 100f  
of gamma cameras. *See* Gamma cameras: photomultiplier tubes of.  
of liquid scintillation counters, 104, 153, 182-183, 206f  
noise reduction and, 184  
magnetic fields and, 197  
of NaI(Tl) detectors, 101-102, 101f-102f  
energy resolution and, 148, 149, 150  
of NaI(Tl) well detectors, 173, 174f, 178, 180  
of PET detectors, 324, 325-326, 325f, 326f, 330, 331, 332  
data corrections and, 335  
in PET/MRI, 360  
power supply for, 122  
in SPECT/CT, 351  
in SPECT/MRI, 360
- Photons, 8. *See also* Annihilation photons; Bremsstrahlung; Gamma rays; X rays.  
annihilation, 25, 25f  
after pair production, 77, 77f  
in annihilation coincidence detection, 307-308, 308f-309f  
interactions with matter, 74-78  
in radiation detectors, 142, 144, 145-146, 145f, 149, 150, 151, 159  
shielding for, 437  
attenuation of. *See* Attenuation.  
backscattered, 75, 166-167, 167f  
bremsstrahlung. *See* Bremsstrahlung.  
coherent scattering of, 77  
Compton scattering of. *See* Compton scattering.  
energies of, 8  
energy deposition by, 64, 77-78, 77f, 78t  
in radiation detectors, 141, 142f  
interactions with matter, 74-78, 78t  
pair production and. *See* Pair production.
- Photons (*Continued*)  
photoelectric effect and, 74, 74f, 77-78, 78t  
secondary, 77, 78t, 141-142  
transmission measurements for, 78-79, 78f  
ultraviolet  
in Geiger-Müller counter, 92, 94  
in scintillation detector, 99-100  
of visible light. *See also* Scintillation detectors.  
in Geiger-Müller counter, 92  
spectrum of, 8, 8f
- Photopeak, 142, 143, 143f, 144, 144f, 145-146, 145f, 146f  
baseline shift and, 146, 147r  
cascaded gamma emissions and, 162, 163  
coincidence detection and, 163  
Compton-scattered gamma rays in, 163-164, 164f  
crystal size and, 145, 146f  
definition of, 142  
gamma-ray energy and, 147  
photofraction in, 159, 160f  
for NaI(Tl) well counter, 174, 175f  
pulse pile-up and, 146, 147f  
selection of, for gamma cameras, 200, 201f  
tail of, with CZT detector, 151  
width of, 149  
window fraction for, 170
- Photopeak detection efficiency of gamma camera, 211, 212f  
intrinsic, of NaI(Tl) well counter, 174, 176f
- Picture archival communications systems (PACS), 367, 378
- Pile-up. *See* Pulse pile-up.
- Pincushion distortion, 199-200, 215f-216f, 216-217
- Pinhole collimators, 202-203, 202f, 225-228  
advantages and limitations of, 228  
collimator resolution of, 225-228, 226f-227f  
source-to-collimator distance and, 228, 228f  
efficiency of, 225-228, 226f-227f  
performance characteristics of, 225-228, 226f-227f  
in reconstruction tomography, 274-275  
in small-animal SPECT, 284-285, 284f-286f, 302
- Pixel depth, 365
- Pixelation effects, 234
- Pixels, 196-197  
addresses of, 364, 364f  
definition of, 364  
display of  
brightness levels in, 364  
colors in, 367  
on flat-panel display, 124  
of gamma camera image, 196-197, 218



- Pixels** (*Continued*)  
 in grayscale displays, 367, 368f  
 in image smoothing, 373, 375f  
 number of, matrix size and, 365-366, 366f  
 of parametric image, 372  
 size of  
   full width at half maximum and, 234  
   spatial resolution and, 365-366  
 of tomographic image, 257  
   in iterative reconstruction, 273, 275  
   SNR of, 267, 268, 269  
   in SPECT, 279, 281, 284, 286f, 289f, 293-294, 296, 297, 299, 301  
 voxels vs., 364
- Planar single-photon imaging**, 1.  
*See also* Gamma cameras.  
 contrast in, 241, 243f  
 selected procedures with, 5t  
 structured noise in, 243
- Plastic scintillators**, 101, 101t  
 pulse signals of, 105, 105f
- Plateau curves**, for Geiger-Müller counters, 94, 95f
- PM tubes**. *See* Photomultiplier (PM) tubes.
- Pocket dosimeters**, 89-90, 90f, 440-441
- Point-spread function (PSF)**, 224f, 235, 263  
 collimator, 222-223, 222f, 224f, 225  
 convolution as, 489, 492  
 modular transfer function and, 238  
 in resolution evaluation, 235  
 scattering and, 297  
 in SPECT, 301
- Poisson distribution**, 126-128, 127f  
 statistical tests and, 133, 134, 135, 149
- Pole zero cancellation**, 112-113
- POPOP** [1,4-di-(2,5-phenyloxazole) benzene], 105
- Position logic circuits**, 196
- Positive ion cyclotron**, 48, 48f, 49
- Positron** ( $\beta^+$ ,  $\gamma$ ) emission, 25, 26
- Positron** ( $\beta^+$ ) emission, 25, 25f, 26  
 competitive with EC, 26, 26f  
 line of stability and, 28
- Positron** ( $\beta^+$ ) emitters  
 cyclotron-produced, 49, 50, 50t  
 historical use of, 2, 313t  
 particle ranges of, 73-74, 73t  
 properties of, 313t  
 radiopharmaceuticals labeled with, 60-61  
 safe handling of, 437, 441  
 scintillation detectors for, 105, 182-183
- Positron decay**, 25-26, 25f
- Positron emission tomography** (PET), 253, 307-343. *See also* Tomographic imaging.  
 absolute quantification in, 339-340
- Positron emission tomography** (PET) (*Continued*)  
 advantages of, 253  
 annihilation coincidence detection in. *See* Annihilation coincidence detection (ACD).  
 applications of  
   clinical, 5t, 341-342, 341f-342f  
   research, 342, 342f  
 attenuation correction in, 338-339, 338f  
 binding potential and, 403  
 in brain imaging, 330-331, 330f  
 in breast imaging, 330-331, 331f  
 calibration factor for, 339-340  
 coincidence counting rates in, 322-324, 322f, 329-330  
   random, 322-323, 322f, 329-330  
   correction for, 336-337  
   estimation of, 336, 340  
   scattered, 322-324, 322f, 329-330  
   correction for, 337-338  
   true, 322-323, 322f  
 coincidence logic in, 307  
 combined with CT scanner, 330  
 contrast in, 241-242, 253, 336, 337, 346  
 co-registered images in, 375-376, 377f  
 current practice of, 4-5  
 data acquisition for, 332-335  
   cross-plane, 332, 333f  
   2-D, 321-322, 332, 333f  
   3-D, 321-322, 332-334, 333f  
   for dynamic studies, 335  
   list-mode, 335  
   for whole-body scans, 335  
 data correction for, 335-340  
   for attenuation, 338-339, 338f  
   for dead time, 339  
   normalization in, 335-336  
   for random coincidences, 336-337  
   for scattered radiation, 337-338  
 dead time in, 339  
 dynamic studies with, 335  
   of receptor binding, 402  
   with FDG, 341-342, 342f  
 Ge-68 rod source in, 328f, 329, 338  
 historical development of, 4  
 image reconstruction protocols for, 340-341  
 for low-contrast imaging, 241-242  
 multi-slice images in, 262-263, 321-322, 332-334  
 in neurodegenerative diseases, 341-342, 342f  
 noise equivalent counting rates and, 340-341, 341f  
 noncolinearity in, 314, 315f, 316  
 in oncology, 341  
 overview of, 1  
 parametric imaging with, 400, 401f  
 partial-volume effects in, 340
- Positron emission tomography** (PET) (*Continued*)  
 point source response profile in, 319  
 principles of, 307-324  
 quantification of, 337, 340, 371f, 372  
 radiopharmaceuticals for, 60  
 receptor binding and, 402-403, 402f  
 regions of interest in, 372-373, 372f, 374f  
 research applications of, 5  
 scintillation detectors for, 104, 316, 324-326, 325f, 326f, 327f, 328, 330-332, 337  
 spatial resolution and, 314-315, 314f  
 sensitivity of, 308, 319-322  
   for 2-D systems, 321-322, 332  
   for 3-D systems, 321-322, 332-334  
 in small animal imaging, 331-332, 331f, 342, 342f  
 spatial resolution in, 310, 311f, 312-319, 312f, 313f, 313t, 314f, 315f, 317f, 318f  
   with block detector, 324-325  
   with cross-plane data, 332  
   cut-off frequency and, 319  
   depth-of-interaction effect in, 316-318  
 detectors and, 310-312, 311f-312f  
   with gamma camera, 329-330  
   geometric efficiency and, 321  
   positron physics and, 312-316, 313f-315f, 313t  
   protocols for, 340-341  
   reconstruction filters and, 319  
   sampling and, 318-319, 318f  
   with specialized systems, 330  
 system resolution in, 314-315  
 systems for, 324-332  
 detectors  
   arrays of, 326-328  
   block, 324-325, 325f, 327f  
   detection efficiency of, 321, 322t  
   geometric efficiency of, 319-322  
   modified block, 325-326, 326f-327f  
   multicoincidence operation of, 320-321  
   phoswich, 326, 327f  
   quadrant-sharing, 325-326, 326f  
   types of, 324-332  
   in whole-body systems, 326-330, 327f  
 gamma cameras, 327f, 329-330  
 performance characteristics of, 340-341  
 scanners, 314, 326-330, 327f  
   multi-ring, 321-322, 332-334, 333f  
 septa of, 323, 324, 328f, 329, 332, 334

- Positron emission tomography (PET) (*Continued*)  
 specialized, 330-332, 330f-331f  
 SPECT systems as, 307, 324  
 in whole-body systems, 326-330, 327f-328f  
 3-D reconstruction, 275-276, 276f  
 time-of-flight, 309-310, 310f  
 timing resolution in, 307-308  
 tomographic reconstruction in, 253, 254, 256. *See also* Tomographic imaging.  
 three-dimensional, 334  
 whole-body studies with, 335, 340, 340f  
 with x-ray CT. *See* PET/CT.
- Positron probes, 194
- Positronium, 25
- Positron-labeled  
 radiopharmaceuticals, 60-61
- Positrons. *See also* Charged particles; Pair production.  
 in annihilation coincidence detection  
 non-collinearity of, 314, 315f, 316  
 ranges of, 307, 312-315, 313f, 314f, 315f, 316  
 spatial resolution and, 312-316, 313f-315f, 313t  
 definition of, 25  
 interactions with matter, 63  
 radionuclides emitting, 312, 313t  
 labeling with, 60-61  
 ranges of  
 in ACD, 307, 312-315, 313f, 314f, 315f, 316  
 average, 73  
 effective, 313, 313f
- Postinjection transmission scans, 338-339
- Potassium-40  
 background radiation from, 184-185  
 total-body potassium and, 194
- Power supplies, high-voltage, 122
- PPO (2,5-diphenyloxazole), 105, 187
- Preamplifiers, 107-110, 108f  
 of gamma camera, 219
- Precalibrated radionuclides, 35
- Precise measurement, 126
- Precursors, radionuclide, 58
- Pregnancy  
 dose limits and, 433, 434t  
 internal dosimetry and, 414  
 occupational exposure in, 437
- Primary ionization events, 141, 142f. *See also* Ionization.
- Primary solute, 105, 106
- Primary spectrum, 147f, 152f
- Probability matrix, 286, 296
- Probable error, 127
- Probes  
 $\beta$ -particle, 194  
 $\gamma$ -ray  
 miniature, 192-194, 193f
- Probes (*Continued*)  
 in oncology, 192-193  
 radiation detectors for, 193
- Production rate, 56
- Projection profiles, 254, 254f, 255, 255f, 256f  
 attenuation correction for, 293, 294  
 backprojection and, 256, 257, 257f, 259, 259f, 260, 261f, 263, 267  
 cone-beam data and, 274  
 fan-beam data and, 273  
 iterative reconstruction  
 algorithms and, 270f, 272  
 scatter component in, 298  
 from transmission scan, 296
- Projection slice theorem  
 definition of, 259  
 in direct Fourier transform reconstruction, 258-260  
 in filtered backprojection, 260-262
- Projection tools, 369-371, 371f
- Projections, 254, 254f
- Proliferation, tracers for, 381t
- Prompt coincidences, 322-324, 322f, 340
- Prompt gamma rays, 45-46
- Propagation of errors, 128-130
- Proportional counters, 91-92, 92f  
 backscatter and, 166-167, 167f  
 dead times of, 168  
 intrinsic efficiency of, 158-159  
 limitations of, 166-167  
 in PET systems, 332  
 power supply for, 122  
 pulse signals of, 108t  
 pulse-height spectrometry with, 153-154  
 self-absorption and, 166-167, 167f  
 for  $\beta$ -emitting radionuclides, 167  
 as gas flow counters, 190
- Protein synthesis, tracers for, 381t
- Protein-binding assays, 173, 189
- Proton deficient nuclides, 17, 28
- Protons, 13-14, 13t. *See also* Charged particles.  
 arrangement of, 14-15  
 in cyclotron, 48, 49f  
 decay modes involving. *See also* specific modes.  
 $\beta^+$  emission as, 25  
 $\beta^-$  emission as, 20  
 electron capture as, 24  
 energy levels of, 10f, 14-15  
 equivalent dose of, 408t  
 forces on, 14-15  
 nuclear stability and, 14-18, 16f-17f  
 number of, 13  
 as particulate radiation, 8  
 properties of, 13, 13t  
 in shell model, 14
- Pseudocolor scale, 367, 368f
- PSF. *See* Point-spread function (PSF).
- PTSM [pyruvaldehyde bis(N-methylthiosemithiocarbazon)], 381t, 394
- Pulse mode, 107
- Pulse pile-up, 112-113, 112f, 146, 147f  
 dead time losses and, 168  
 with gamma cameras, 213-216  
 correction of, 214-216  
 counting losses and, 213-214, 213f  
 dead time losses and, 213-214  
 image distortion and, 214-216, 214f-215f  
 in PET, 339  
 in pulse-height spectrometry, 146, 147f  
 pulse-tail extrapolation for, 214-216, 215f
- Pulse resolving time. *See* Dead time/dead time losses.
- Pulse shaping  
 by amplifier, 111-112, 112f  
 by preamplifier, 107-108, 108t  
 in rate meter, 120
- Pulse signal of various radiation detectors, 107, 108t
- Pulse-height analyzers (PHAs), 113-118, 114f, 115f, 116f, 117f  
 dead time losses and, 168  
 energy-selective counting with, 156, 158, 159, 160f  
 of gamma camera, 142-147, 143f, 145f, 146f, 147f, 151  
 energy resolution and, 212, 212f, 213  
 image corrections with, 218  
 image contrast and, 240, 241f  
 multichannel, 113, 116-118, 116f  
 of liquid scintillation counters, 184  
 of NaI(Tl) well counters, 173, 180f, 181  
 of semiconductor detectors, 190  
 as nonparalyzable systems, 168  
 object scatter and, 144, 145, 147  
 in PET, 337  
 principles and design of, 113, 114f  
 processor chip for, 363  
 single-channel, 113-116, 114f  
 dead times of, 168  
 NaI(Tl) well counters and, 173, 178, 181  
 timing methods for, 114-116, 115f  
 spectral blurring in, 144, 148-151  
 window fractions and, 170-171
- Pulse-height spectrometry, 116f, 117, 141-154  
 dead time losses in, 168, 170  
 with liquid scintillation counters, 141, 153, 153f, 184, 185f  
 multichannel analyzer in, 113, 116-118, 116f, 141  
 with NaI(Tl) detectors, 142-151  
 actual spectrum for, 143-145, 143f-147f  
 counting rate and, 146, 147f

Pulse-height spectrometry  
(*Continued*)  
detector size and, 145-146,  
146f  
energy linearity and, 147-148,  
148f  
energy resolution and, 148-151,  
149f. *See also* Energy  
resolution.  
gamma-ray energy effects in,  
146-147, 147f  
ideal spectrum for, 142-143,  
143f  
primary spectrum for, 147f  
scatter spectrum for, 147f  
principles of, 141-142  
with proportional counters,  
153-154  
quality assurance checks of, 172  
with semiconductor detectors,  
151-153, 151f-152f  
two-energy window analysis and,  
184  
Pulse-resolving time. *See* Dead  
time/dead time losses.  
Pulse-tail extrapolation, 214-216,  
215f  
Purity  
chemical, 59  
radiochemical, 59  
radionuclidic, 58  
semiconductor detectors of,  
190, 191  
PXE (phenylxylethane), 105, 187

## Q

Q. *See* Transition energy (Q).  
Quadrant sharing, 325-326, 326f  
Quality assurance, 171-172. *See  
also* Image quality.  
for gamma cameras, 228-231  
for NaI(Tl) well counters, 178  
for radiopharmaceuticals, 182  
for SPECT, 302-303  
Quanta, 8  
Quantities, physical, 7-8  
Quantum efficiency, 98, 99f  
Quantum mottle, 243  
Quantum numbers, 9, 10f, 14  
Quench correction, 106  
automatic external  
standardization method for,  
186-187, 187f  
channel ratio method for, 186  
internal standardization method  
for, 186, 186f  
for liquid scintillation counters,  
185-187, 186f-187f  
Quenching, 106  
Quenching gases, 93-94

## R

Rad, 407  
Radiation, 8-9. *See also* Charged  
particles; Photons.  
accidental ingestion of, 437-438  
background  
effective dose from, 431  
sources of, 177-178, 431

Radiation (*Continued*)  
Cerenkov, 68-70  
characteristic, 10-13, 11f, 12t  
definition of, 8  
GM counters for, 92  
electromagnetic, 8-9, 66  
emission of. *See* Emissions.  
forms of, 8, 8f  
ionizing, 63  
biologic effects of, 78, 427-428  
definition of, 63, 87  
secondary, 74  
long-term health effects of, 427  
particulate, 8  
penetrating, 82-83  
scattered. *See* Scattered  
radiation.  
Radiation biology, 407  
Radiation counting rate. *See*  
Counting rates.  
Radiation counting systems. *See*  
Counting systems.  
Radiation detectors, 87-106, 122.  
*See also* Gas-filled detectors;  
Scintillation detectors;  
Semiconductor detectors;  
specific types.  
amplifiers for, 110-113  
for annihilation coincidence  
detection, 309-310  
coincidence detection and,  
162-163  
coincidence units and, 121-122  
dead areas of, 267f. *See also*  
Dead time/dead time losses.  
digital counters and, 119-121  
efficiency of, 155-166. *See also*  
Detection efficiency.  
energy deposition in, 91, 141,  
142  
high-voltage power supplies for,  
122  
instrumentation for, 107-124  
nuclear instrument modules and,  
122-123  
as paralyzable systems, 168-169,  
168f-169f  
phoswich, 326, 327f  
preamplifiers in, 107-110, 108f  
in pulse mode, 107  
pulse output of, 107, 108t  
pulse-height analyzers and,  
113-118, 114f  
quadrant-sharing, 325-326,  
326f  
quality assurance for, 171-172  
rate meters and, 119-121  
signal output of, 108t  
spectral blurring with, 144,  
148-151  
thickness of  
depth of interaction and,  
316-317, 317f  
intrinsic spatial resolution and,  
210, 211f  
time-to-amplitude converters  
and, 118-119, 119f  
Radiation dose, 407-408. *See also*  
Radiation safety.  
absorbed, 432-435, 433t  
air kerma and, 434, 438-439

Radiation dose (*Continued*)  
average, 414, 424, 427,  
428  
estimation of, 434  
radiation safety and, 427, 428,  
429t, 434t  
scaling factor for, 430, 430f  
units for, 428-431  
air kerma and, 434-436.  
*See also* Air kerma.  
in bone, 434  
calculation of. *See* Absorbed  
fraction (MIRD) method;  
Radiation dosimetry,  
internal.  
choice of radionuclide and, 57  
contaminants and, 58  
cumulated activity and, 409-410,  
424  
definition of, 407  
distance from source and,  
435-436  
dose calibrators for, 89, 89f,  
189-190, 437  
effective, 417, 425t, 429t  
from background radiation,  
427  
equivalent, 407-408, 429t  
air kerma and, 434-436  
distance from source and,  
435-436  
half-life and, 57, 58  
information sources for, 422  
internal. *See also* Radiation  
dosimetry, internal.  
avoidance of, 440-441  
limits on, 431-432, 432t, 433,  
434t  
mean, per unit cumulated  
activity, 415-417  
for F-18, 422t-423t  
for I-131, 420t-421t  
for Tc-99m, 418t-419t  
occupational limits for, 431-433,  
434t. *See also* Radiation  
safety.  
scaling factor for, 430, 430f  
surface, 409  
tissue weighting factors for, 417,  
425t  
units of, 407-408, 408t, 428,  
429-430  
whole-body (total-body), 417,  
425t  
Radiation dose-modifying factors,  
428  
Radiation dosimetry, internal, 2,  
407-425. *See also* Organs.  
absorbed fraction in, 413-414,  
414f  
specific, 414-415  
anatomic models for, 409, 414,  
414f, 415t, 424. *See also*  
Phantoms.  
basic procedure in, 408-409,  
409f  
classic method in, 407  
cumulated activity in, 409-412,  
410f, 411f  
average absorbed dose and,  
414, 424, 427, 428

- Radiation dosimetry, internal  
(*Continued*)  
mean dose per unit of, 415-417  
for F-18, 422t-423t  
for I-131, 420t-421t  
for Tc-99m, 418t-419t  
problems in determination of, 424  
dose in. *See* Radiation dose.  
effective dose equivalent in, 417, 425t, 427, 429t, 478-479  
effective dose in, 417, 425t, 427, 429t, 433t  
equilibrium absorbed dose  
constant in, 412-413  
future directions for, 424-425  
information sources for, 422  
limitations of MIRD method in, 424-425  
MIRD Committee and, 407, 414  
quantities and units in, 407-408, 408t  
reciprocity theorem in, 414-415  
therapeutic applications of, 416-417, 428
- Radiation energy losses, 64-65, 66f-67f
- Radiation hormesis, 431
- Radiation losses, 64-66, 67, 67f, 68
- Radiation monitoring, 439-441, 440f. *See also* Radiation safety; Survey meters.  
laboratory monitors for, 440  
personnel dosimeters for, 89-90, 90f, 440-441, 440f  
survey meters for, 89, 89f, 439-440  
wipe testing for, 441
- Radiation safety, 2, 427-442.  
*See also* Health physics.  
air kerma and, 428-431, 434-435  
airborne materials and, 432, 432t, 438  
background radiation and, 427  
biologic effects and, 427-428  
decontamination in, 439  
distance from source and, 435-436  
dose-modifying factors and, 428  
exposure and, 428-431  
general public and, 431, 432, 433t, 434t  
government regulations for, 431-433  
advisory boards and, 433  
for airborne radioactivity, 432, 432t-433t  
for dose limits, 431-432, 435-436  
Nuclear Regulatory Commission (NRC) and, 431, 432, 433  
for record keeping, 432-433  
for restricted and unrestricted areas, 431  
for sewage disposal, 432, 433t  
information sources for, 427-428  
for internal sources, 437-438  
laboratory design and, 438
- Radiation safety (*Continued*)  
material handling and, 433-439  
ALARA concept and, 433-434  
dose reduction from external sources, 434-435  
monitoring and. *See* Radiation monitoring.  
NCRP recommendations for, 431, 433, 434t  
quantities and units in, 428-431, 429t, 430f  
for radioactive gases, 438  
shielding and. *See* Shielding.  
sources of exposure and, 427  
spills and, 437  
TDS rules and, 436-437  
waste disposal and, 439
- Radioactive decay, 19-29. *See also* Activity; Radionuclides.  
by alpha emission, 26-28  
average lifetime and, 34  
chemical properties and, 19-20  
decay constant in, 31, 32, 33, 34  
decay factors in, 32-33, 33f  
approximation to, 32, 32f, 33  
determination of, 34-35  
effective, 35-37, 36f  
tables of, 34, 34t  
decay scheme diagrams for, 20-21, 20f  
of important radionuclides, 449-475  
decay series and, 27-28, 27f  
definition of, 19  
general concepts of, 19  
half-life and, 33-34  
image-free decay corrections and, 35-36, 36f  
by internal conversion, 22-24  
isobaric, 20  
isotope effect and, 20  
line of stability and, 16, 16f, 28  
mass-energy conversion in, 19  
transition energy and, 19, 20, 20f, 21, 21f, 24  
of mixed samples, 38-42, 39f  
parent-daughter, 39-42. *See also* Parent-daughter decay.  
of unrelated species, 38-39, 39f  
modes of, 20-28. *See also* specific modes.  
alpha-particle emission as, 26-28  
by  $\beta^+$ ,  $\gamma$  emission, 25-26  
by  $\beta^-$ ,  $\gamma$  emission, 21-22, 22f  
by  $\beta^+$  emission, 26-28  
by  $\beta^-$  emission, 20-21f  
competitive  $\beta^+$  and EC as, 26  
EC, 24-25  
(EC,  $\gamma$ ), 24-25  
internal conversion as, 22-23, 23f  
by isomeric transition, 22-24  
nuclear fission, 28  
overview of, 19  
positron emission, 25-26, 25f  
rate of, 31  
series, 27-28, 27f  
transition energy in, 19, 20, 20f, 21, 21f, 22, 24
- Radioactive disintegration, 16
- Radioactive gases, safety measures for, 438
- Radioactive spills, handling of, 438
- Radioactive tracers, stability of, 19-20
- Radioactive waste disposal, 439
- Radioactivity. *See also* Radioactive decay.  
discovery of, 2, 9  
natural, as background, 177, 427, 432
- Radioactivity, from internal sources, 437-438. *See also* Radiation dosimetry, internal.
- Radiobiology, 407
- Radiochemical purity, 59
- Radioimmunoassays, 173, 182, 189
- Radioisotope, 19. *See also* Isotopes; Radionuclides.
- Radioligands, 401
- Radionuclide imaging, 195-196. *See also* Gamma cameras; Tomographic imaging.
- Radionuclides, 19
- Radionuclides. *See also* Radiopharmaceuticals.  
activity of. *See* Activity.  
average lifetime of, 34, 82  
cumulated activity and, 410, 411f  
as calibration standards, 164-166, 165t  
carrier-free, 37-38  
chemical properties of, 58  
Compton-scattered photons from, 75-76, 75t  
contaminants in  
detection of, 39  
effects of, 58  
in generator systems, 53, 58  
decay of. *See* Radioactive decay.  
definition of, 19  
dose calculations for, 424-425  
dose-rate constants of, 434, 435t  
emissions from, 57, 58t  
fission fragments of, 28, 44-45, 45f  
half-life of, 33-35, 57, 58t  
cumulated activity and, 410-412  
information sources for, 28, 29f  
line of stability and, 16, 16f, 28  
medically important, 57-59, 58t  
characteristics of, 57-59, 58t, 449-475  
cyclotron-produced, 49-50, 50t  
generator-produced, 3, 24, 50-53, 51f-52f, 51t  
neutron-activated, 45-47, 46t  
metastable, separation of, 24  
naturally occurring, 427  
neutron-activated, 45-47, 46t  
positron-emitting, 312, 313t  
labeling with, 60-61  
precalibrated, 35  
production of, 43-61  
in accelerators, 47-50, 49f-51f, 50t  
charged-particle, 47, 50t



- Radionuclides (Continued)**  
 activity buildup and decay in, 56  
 in cyclotrons, 47-50, 50t  
 equations for, 53-57  
 in generators, 3, 24, 50-53, 51f-52f, 51t  
 contaminants and, 53, 58  
 safe handling of, 433-434  
 historical perspective on, 2  
 in reactors, 43-47, 46t  
 properties of, 19, 57-59, 58t  
 purity of, 58  
 specific activity of, 57-58  
 for transmission scans  
 in PET, 338, 339, 342  
 in SPECT, 294-295, 296, 300f
- Radionuclidic purity, 58**  
 semiconductor detectors of, 190-191
- Radiopharmaceuticals, 1, 2, 5t, 59-61, 379, 380**  
 analog, 60, 61, 382  
 applications of, 5t, 60t  
 therapeutic, 61  
 approval process for, 2, 424  
 assays of  
 semiconductor detectors for, 191  
 well counters for, 182  
 biologic half-life of, 59, 417  
 chemical properties of, 19-20  
 in clinical nuclear medicine, 61  
 commonly used, 5t, 60t, 381t  
 cumulated activity of.  
*See* Cumulated activity.  
 definition of, 57  
 diffusible, 394-395  
 distribution of, 409  
 dose estimates for, 425, 478-479  
 dosimetry for, 2  
 examples of, 5t, 60t, 381t  
 for FDG-PET, 341-342  
 ideal, 380  
 impurities in, 59  
 assay of, 191  
 in  $^{99m}\text{Tc}$ , 51-53, 58, 85  
 labeling strategies for, 59-60  
 as metabolic tracers, 380.  
*See also* Fluorodeoxyglucose (FDG); Methylene diphosphonate (MDP); Oxygen-15.  
 microdosimetry of, 425  
 nondiffusible, 394  
 positron-labeled, 60-61  
 production of, 57-61  
 properties of, 59-61  
 purity of, 59  
 radionuclides for. *See* Radionuclides: medically important.  
 safety of, 59  
 specific activity of, 59  
 for SPECT, 304-306  
 $^{99m}\text{Tc}$ -labeled, 60, 60t.  
*See also* Technetium-99m.  
 therapy applications of, 61, 425  
 in tracer kinetic modeling, 380-382, 381t
- Radiotracer(s). *See* Radionuclides; Radiopharmaceuticals; Tracer kinetic modeling.**
- Radium-226, 27-28**  
 curies and, 32
- Rainbow scale, 367, 368f**
- Ramp converters, 117-118, 117f**
- Ramp filter, 260-261, 261f-262f**  
 image quality and, 268, 269, 301  
 in SPECT, 301
- Random coincidences, 322-323, 322f, 329-330**  
 corrections for, 336-337  
 estimation of, 336, 340  
 with gamma camera, 332  
 septa and, 332
- Random error, 125-126, 128**  
 statistical significance and, 130, 131, 134
- Random noise. *See* Statistical noise.**
- Range of charged particles, 70-74, 70f, 72f-73f, 73t**  
 average, 73-74  
 effective, 313, 313f  
 extrapolated, 71-74, 72f-73f  
 mean, 70
- Range straggling, 70, 70f**
- Rate constants, 384-385, 384f, 385f, 390-391, 390f**  
 of enzymatic reaction, 396
- Rate detectors, coincidence units and, 121-122**
- Rate meter time constant, 120**
- Rate meters, 119-121**  
 analog, 120-121, 120f  
 logarithmic, 121, 121f
- Rayleigh scattering, 77**
- RBCs. *See* Red blood cells (RBCs).**
- RC pulse shaping, 111-112, 112f**
- RCs. *See* Recovery coefficients (RCs).**
- Reaction rate, of enzymatic reaction, 396, 398f**
- Reactors, nuclear, 43-44, 44f**  
 neutron-capture cross sections in, 54  
 principles and design of, 43-44, 44f  
 radionuclide production in, 43-44, 46t
- Receiver operating characteristic (ROC) studies, 248-251, 250f**
- Receptor ligand assays, 401-403, 402f, 404f**  
 tracers for, 381t
- Recoil electrons, 74-76, 75f, 75t, 78t, 144**  
 pulse-height spectrum and, 142, 144
- Reconstruction algorithms. *See* Tomographic imaging: mathematical techniques in.**
- Reconstruction filters, 260-261, 263, 264f**  
 Hann, 261, 262f  
 in PET, 319  
 ramp, 260-261, 261f-262f  
 in SPECT, 301
- Reconstruction filters (Continued)**  
 Shepp-Logan, 261, 262f, 263-265, 264f  
 spatial resolution and, 267, 269  
 in PET systems, 319  
 in SPECT systems, 302, 303f
- Reconstruction tomography**  
 backprojection in, 256-258, 266f  
 collimators in  
 cone-beam, 274-275, 274f  
 fan-beam, 273-274, 274f-275f  
 parallel-hole, 273  
 cone-beam, 273-275, 274f  
 coordinate systems for, 255, 256f  
 direct Fourier transform, 258-260, 259f-260f  
 emission CT in, 253  
 expectation-maximization reconstruction in, 272-273  
 fan-beam, 273-276, 274f-275f  
 Feldkamp algorithm in, 275  
 filtered backprojection in, 260-262  
 image quality in, 263-270  
 coverage and consistency requirements and, 266  
 Nyquist frequency and, 263  
 sampling and, 263-265  
 iterative reconstruction algorithms in, 262, 270-273.  
*See also* Iterative reconstruction.  
 multi-slice imaging in, 262-263  
 noise in, 266-268  
 overview of, 254-256  
 in PET, 319, 340-341  
 3-D, 275-276, 276f  
 projection profiles for, 254-256, 254f-256f  
 sinograms and, 255-256, 256f  
 ramp, 260-261, 262f  
 in SPECT, 301  
 response characteristics and, 254-256, 254f  
 Shepp-Logan, 261, 262f, 263-265, 264f  
 in SPECT, 301-303  
 transmission CT in, 253  
 in x-ray CT, 348-350, 349f
- Record-keeping regulations, 432-433**
- Recovery coefficients (RCs), 299, 300f**
- Rectilinear scanner, 195-196**
- Red blood cells (RBCs)**  
 in cardiac studies, 392, 392f  
 clumping of, by aluminum ion, 53  
 distribution volume of, 383
- Reference sample technique, 393**
- Reference scan, 295**
- Regions of interest (ROI), 372-373, 372f**  
 kinetic modeling and, 379, 391, 400, 404  
 time-activity curves and, 373, 374f
- Registration algorithm, 296**

- Regression analysis, 390  
 linear, 139-140  
 in tracer kinetic modeling, 390
- Regulations, U.S. government, 431, 432, 433, 435-437, 436t-437t
- Rem, 408, 430
- Renal function, evaluation of, 379
- Renkin-Crone model, 387-388, 388f-389f, 390-391
- Reproducibility of measurements, 126
- Resistor-capacitor pulse shaping, 111-112, 112f
- Resolution. *See* Energy resolution; Spatial resolution; Timing resolution.
- Resolution volume of SPECT system, 301-302
- Respiratory motion. *See* Motion blurring.
- Restricted areas, 431  
 radiation levels in, 431-432
- Rest/stress studies, 303
- Ring dosimeters, 440-441, 440f
- Ringing artifacts, 486
- Ripple in HV power supply, 122
- Rise time  
 of electronic signal, 111, 112  
 of scintillator light output, 309
- ROC studies. *See* Receiver-operating characteristic (ROC) studies.
- Rod standards, 164, 165f
- Roentgen, Wilhelm, 2
- Roentgens, 89, 90, 429-430
- ROI. *See* Regions of interest (ROI).
- Rollo phantom, 247-248, 248f
- Root mean square effective range, 314
- Rose criterion, 244, 269
- Rubidium-82, properties of, 58t
- Rutherford, Ernest, 9
- Rutherford atomic model, 9
- S**
- Safety. *See* Radiation safety.
- Safety concerns. *See* Radiation safety.
- Sagittal sections, orientation of, 369, 370f
- Sample volume  
 with dose calibrator, 189-190  
 with NaI(Tl) conventional detector, 182  
 with NaI(Tl) well counter, 174, 175-177, 177f
- Samples, dark adaptation of, 185
- Sampling, 263, 264f, 265-266, 265f, 481, 482, 484, 487  
 in annihilation coincidence detection, 318-319, 318f  
 performance measurement and, 301  
 pixel size and, 366  
 preparation for liquid scintillation counters, 106, 187-188  
 SNR and, 268
- Sampling interval. *See* Angular sampling intervals; Linear sampling distance.
- Sampling theorem, 263, 366, 483, 484, 485
- Saturation region, 87-88, 88f
- Saturation specific activity, 56
- Saturation voltage, 87-88, 88f
- Scalers, 119-120  
 dead times of, 168
- Scaler-timers, 119-120, 119f  
 dead time losses in, 168
- Scaling factor, for absorbed dose, 427, 430
- Scanner, rectilinear, 195-196
- SCAs. *See* Single-channel analyzers (SCAs).
- Scatter coincidences, 322-324, 322f  
 with 3-D data acquisition, 332, 334  
 with gamma camera, 329-330  
 septa and, 329  
 transmission scanning and, 339  
 uncertainty in, 336, 337
- Scatter correction  
 in PET, 337-338  
 in SPECT, 296-299, 297f, 298f, 302
- Scatter window, 298, 298f
- Scattered radiation, 166-167, 167f  
 background counting rates and, 240-241, 241f  
 backscattered, 75, 143f, 144, 166-167, 167f  
 beam geometry and, 80, 81, 81f, 84  
 coherent, 77  
 in SPECT, 297  
 Compton-scattered. *See* Compton scattering.
- detection efficiency and, 156, 163-164
- downscattered, 296
- in gamma camera, 200, 204, 205, 209  
 counting losses and, 213-214, 213f  
 energy resolution and, 212  
 as multiple scattering, 209, 210  
 image contrast and, 240-241, 242f  
 object scattered, 144-145, 205  
 in PET, 322-323, 322f, 329-330  
 correction for, 337-338  
 in PET/CT, correction of, 337, 356-360  
 in pulse-height spectrometry, 141, 212-213
- Rayleigh scattering and, 77
- scatter windows and, 298, 298f
- in SPECT, 286, 296, 299, 302  
 correction of, 296-299
- object scatter as  
 with gamma camera, 205, 205f  
 with Ge(Li) detector, 152f  
 with NaI(Tl) detector, 144, 145, 147, 147f, 152f
- Scattered radiation (*Continued*)  
 in vivo probe measurements and, 192  
 window fraction and, 170  
 in SPECT/CT, correction of, 356-360  
 in x-ray computed tomography (CT), 349
- Scintillation cameras, timing methods for, 114-115
- Scintillation detectors, 97-106.  
*See also* Radiation detectors.
- amplifiers for, 111  
 for intraoperative gamma probes, 194
- NaI(Tl), 100-103, 101f-103f, 101t. *See also* NaI(Tl) detectors.
- for PET systems, 104, 316, 324-326, 325f, 326f, 327f, 328, 330-332, 337  
 spatial resolution and, 314-315, 314f
- photodiodes in, 99-100
- photomultiplier tubes for, 98-99, 100f-101f, 101-102  
 with inorganic scintillators, 100-103, 101f-103f  
 with organic scintillators, 105f
- power supplies for, 122
- preamplifiers for, 109, 110
- principles and design of, 97-98, 98f
- spectral blurring with, 148
- time-to-amplitude converters for, 118
- Scintillators, 97  
 background noise associated with, 184  
 effective atomic number of, 103  
 energy response of, nonlinear, 148, 149-150  
 inorganic, 100-103, 101f, 101t, 102f, 103f  
 NaI(Tl), 100-103, 101f-103f, 101t. *See also* NaI(Tl) detectors.
- for PET, 316, 322t, 324, 326  
 properties of, 101t, 103, 103f  
 selection of, 103
- organic, 104-106  
 in liquid solution, 97, 104-106, 106f, 185, 187, 188  
 plastic, 105, 105f  
 solid, for flow counter, 187
- SD. *See* Standard deviation (SD).
- Secondary electrons, 63, 64f, 66, 67f, 78t  
 in photomultiplier tubes, 98-99, 100f
- Secondary emission in photomultiplier tube, 98
- Secondary ionization, 63, 64f, 141-142, 142f
- charged-particle interactions and, 63, 68
- photon interactions and, 77, 78t, 141-142

- Secondary ionizing radiation, 74
- Secondary photons, 77, 78t, 141-142
- Secondary solute, 105, 106
- Secular equilibrium, 40-41, 40f
- Segmentation, image, 357, 375, 377f
- Self-absorption, 167, 167f  
quench correction and, 187
- Semiconductor detectors, 96-97, 97f, 190-192, 191f. *See also* Radiation detectors.  
advantages of, 96, 190-191, 240  
amplifiers for, 111, 112, 113  
applications of, 190-192  
cadmium telluride, 96-97  
cadmium zinc telluride, 96-97  
dead times of, 168  
design of, 97, 97f  
detection efficiency of, 151, 158, 164, 190  
efficiency of, 158, 190-191  
energy resolution of, 151-152, 152f, 190-192, 191f, 240  
for gamma-ray probes, 193  
germanium, 96-97  
intraoperative gamma probe as, 193f, 194  
limitations of, 96, 102, 190  
lithium-drifted, 96-97, 97f  
power supplies for, 122  
preamplifiers for, 107-110, 108f  
pulse signals of, 108t  
pulse-height spectrometry with, 151-153, 151f-152f  
silicon, 96-97  
applications of, 190  
in scintillation detectors, 99-100
- Semiconductor photodiodes.  
*See* Silicon photodiodes.
- Sensitivity  
of collimator  
in gamma camera, 223, 224f, 225t, 227, 231  
lesion detectability and, 246, 247f  
of PET, 308, 319-322  
with 2-D data acquisition, 321-322, 332  
with 3-D data acquisition, 321-322, 332-334  
of receiver operating characteristic, 249
- Sentinel nodes, gamma-ray probes for, 192-193
- Septal penetration, 205, 220-221  
background counting rates and, 240  
image contrast and, 240-241, 242f  
line-spread function and, 240-241, 242f  
pinhole collimators and, 227
- Septal thickness in collimators, 203, 203f, 211, 220-221, 220f-221f
- Series decay, 27-28, 27f
- Sestamibi, <sup>99m</sup>Tc-labeled, 5t, 60t  
blood flow measurement with, 381t  
dose estimates for, 480  
SPECT imaging with, 5t, 303f, 304, 304f, 305
- Sewage, dose limits and, 432, 433t
- Shallow-dose equivalent, 432
- Shell model of nucleus, 14
- Shells, electron, 9-13
- Shepp-Logan filter, 261, 262f, 263-265, 264f
- Shielding, 82t, 436-437, 436f  
of  $\alpha$  particles, 71  
background counting rates and, 240  
backscatter from, 144  
beam geometry and, 82, 83  
of  $\beta$  emitter, 65, 66f, 437  
Bremsstrahlung, 65, 67f  
of dose calibrators, 189-190, 189f, 437  
effectiveness of, 437  
lead. *See* Lead shielding.  
methods of, 436-437, 436f  
Mu-metal, 99, 101f  
for NaI(Tl) well counters, 177-178  
natural radioactivity in, 177-178  
pulse pile-up and, 214, 215f  
for radiation safety, 436-437, 436f  
TDS rules and, 436  
tenth-value thickness and, 82, 82t, 437  
of whole-body counting chambers, 194  
x-ray peaks caused by, 144, 151
- Shunt, intracardiac, detection of with labeled microspheres, 394  
with labeled RBCs, 392
- SI. *See* specific ionization (SI).
- SI units. *See* Systeme International (SI) units.
- Sievert (Sv), 408, 417, 428, 430
- Signal amplification. *See* Amplifiers; Preamplifiers.
- Signal-to-noise ratio (SNR), 110.  
*See also* Noise.  
amplifier time constant and, 110  
in filtered backprojection, 260-261, 263, 264f  
image smoothing and, 373, 375f  
preamplifier location and, 110  
in time-of-flight PET, 309, 310  
in tomographic reconstruction, 261, 263, 266-268
- Silicon detectors, 96-97. *See also* Radiation detectors; Semiconductor detectors.  
energy resolution of, 190  
intrinsic efficiency of, 158  
lithium-drifted, 89t, 96-97, 97f  
in scintillation detectors, 99
- Silicon photodiodes, 99-100  
avalanche, 100, 332  
in compact gamma camera, 207  
in gamma-ray probes, 193, 193f
- Simple backprojection, 256-258, 266f. *See also* Reconstruction tomography.  
filtered backprojection vs., 260-261
- Simultaneous emission/transmission scans in PET  
attenuation correction, 338-339
- Single escape peaks, 144, 145f
- Single photon emission computed tomography (SPECT), 253, 279-306. *See also* Tomographic imaging.  
advantages of, 253  
artifacts in, 286, 302  
attenuation in, 285-293, 291t-292t  
conjugate counting and, 287  
correction of, 293-294  
Chang multiplicative method, 294, 294f, 296, 297f  
scatter correction and, 296-299, 298f  
transmission scans and, 294-296, 295f-297f  
attenuation maps for, 294-296, 296f  
binding potential and, 403  
blank scans in, 295  
blood flow measurements with, 393, 395  
in brain imaging, 280-281, 282f, 304-305, 304f  
in cancer, 305-306  
in cardiac imaging, 281-283, 303, 305f, 306  
center of rotation in, 302-303  
CERASPECT system for, 280-281, 282f  
clinical applications of, 303-306, 303f-305f  
collimators in  
converging, 279-280  
parallel-hole, 279-281  
combined with x-ray CT. *See* SPECT/CT.  
contrast in, 241-242, 243f, 297, 299  
co-registered images in, 376  
current practice of, 4-5  
3-D, 364  
detector head orbits in, 280, 280f  
distortion sources and, 286  
downscatter in, 296  
dynamic  
FASTSPECT system for, 279-278, 284, 286f  
for receptor binding studies, 402  
flood-field uniformity in, 302  
gamma cameras for, 279-280  
historical development of, 4  
image quality in, 302-303  
image reconstruction in, 301-303  
imaging speed in, 280-281  
limitations of, 280

- Single photon emission computed tomography (SPECT)  
(*Continued*)  
for low-contrast imaging, 241-242  
multislice systems for, 280f,  
281-299  
multiple detector heads in, 279  
multislice images in, 262-263  
performance characteristics of,  
299-303  
count-rate performance, 302  
dead time, 302  
energy resolution, 302  
spatial resolution, 301  
volume sensitivity, 301-302  
practical implementation of,  
285-299  
attenuation corrections in,  
293-294, 294f  
conjugate counting in, 287,  
288f  
idealized assumptions and,  
285-286  
partial-volume effects in, 299,  
300f, 373  
scatter corrections in, 296-299,  
297f, 298f, 302  
transmission scans in, 294-296,  
295f-297f  
vs. idealized assumptions, 286  
quality assurance for, 302-303  
quantitative images in, 372  
radiopharmaceuticals for,  
304-306  
recovery coefficients for, 299,  
300f  
reference scans in, 295  
regions of interest in, 372-373  
research applications of, 3, 403  
sensitivity of, 308, 321-322  
in small-animal imaging,  
283-285, 286f, 305f, 306  
spatial resolution in, 280, 280f,  
281, 283, 284, 288, 289, 298,  
299, 300f, 301  
SPECT/CT vs., 351-352  
spillover in, 299  
SPRINT II system for, 280-281,  
282f  
system alignment in, 302-303  
systems for, 279-281, 280f, 282f,  
283-285, 283f, 284f, 285f,  
286f  
used for PET, 307, 324  
tomographic reconstruction in,  
253, 254, 255, 256  
volume sensitivity in, 301-302
- Single photon planar imaging, 1,  
5t, 241, 243, 243f. *See also*  
Gamma cameras.
- Single-channel analyzers (SCAs),  
113-116, 114f, 118, 122  
counting rate and, 146-147  
dead times of, 168  
of NaI(Tl) probe system, 207  
NaI(Tl) well counters and, 173,  
178, 181  
for radiochemical identification,  
181
- Singles method for random  
coincidences, 337
- Sinograms, 255-256, 256f, 270f,  
271, 276
- Skin. *See also* Organs.  
contaminated, 439  
dose to, 428, 432, 434, 434t  
Slant-hole collimators, 203
- Slice thickness, 301  
in PET, 329  
in SPECT, 301
- Slow neutrons, 43-44
- Small-animal imaging  
3-D iterative reconstruction in,  
276  
gamma cameras for, 207-208  
PET in, 331-332, 331f, 342,  
342f  
PET/CT in, 356, 356f  
SPECT in, 283-285, 286f, 305f,  
306  
SPECT/CT in, 352-354, 353f  
Smoothing, image, 373, 375f
- Sn-113, as calibration standard,  
165t
- SNR. *See* Signal-to-noise ratio  
(SNR).
- Sodium-22, 165t
- Sodium iodide, 479t
- Sodium iodide detectors. *See*  
NaI(Tl) detectors.
- Sokoloff deoxyglucose method, 397,  
400
- Somatostatin receptors, 2, 305
- Source organs, 408, 413-414, 415,  
416, 418t-424t
- Source-to-collimator distance  
collimator resolution and, 223,  
224f, 227-228, 227f-228f  
modulation transfer function  
and, 238, 238f  
in SPECT, 284
- Spatial frequency, 236  
Fourier transform and, 260f, 263,  
481, 483, 484, 485f, 486f,  
487, 492  
pixel size and, 366  
resolution and, 236, 237-238,  
237f, 238, 239f
- Spatial frequency space.  
*See* k-space.
- Spatial linearity of gamma  
cameras, 229-230
- Spatial resolution, 233-239.  
*See also* Image quality.  
axial, 301  
background subtraction and,  
242-243  
collimator, 234. *See also*  
Collimator resolution.  
contrast enhancement and,  
242-243  
cut-off frequency and, 319  
definition of, 209-211, 233-234  
detectability and, 246-247  
evaluation of, 234  
full width at half maximum  
and, 235-236  
line-spread function in, 235  
modulation transfer function  
in, 233, 236-237,  
237f-238f  
objective, 234-239
- Spatial resolution (*Continued*)  
phantoms in, 234-235,  
234f-235f  
point-spread function in, 235  
spatial frequency in, 245  
subjective, 234  
factors affecting, 233-234, 235f  
in-plane, 301  
intrinsic, 234  
Compton scattering and,  
209-211, 210f-211f  
detector thickness and, 210,  
211f  
full width at half maximum  
and, 210-211, 221, 225t,  
229  
of gamma cameras, 209-211,  
210f-211f, 219, 234  
bar phantom and, 235, 235f  
in coincidence detection, 310,  
311f-312f  
measurement of, 229  
MTF for, 238  
in PET systems, 329  
in SPECT systems, 299,  
300f  
system resolution and, 229  
 $\gamma$ -ray energy and, 210, 210f  
limits on, 209-210  
measurement of, 210, 229  
optimum, 210-211  
system resolution and,  
210-211, 225, 227  
lesion detectability and, 248,  
249f  
linear sampling distance and,  
263, 365-366, 373  
matrix size and, 365-366, 366f  
patient motion and, 234  
in PET. *See* Positron emission  
tomography (PET): spatial  
resolution in.  
pixel size and, 365-366  
pixelation effects and, 234  
reconstructed, measurement of,  
301. *See also* Reconstruction  
tomography.  
smoothing filter and, 375f  
in SPECT, 280, 280f, 281, 283,  
284, 288, 289, 298, 299, 300f,  
301  
system resolution as. *See* System  
resolution.  
tomographic reconstruction and  
collimator types and, 273, 279  
cutoff frequency and, 263, 264f,  
301, 319  
with iterative algorithms,  
273-274  
sampling and, 265, 266, 267  
transaxial, 301  
in x-ray CT, 349
- Specific absorbed fraction,  
414-415
- Specific activity, 37-38  
carrier-free, 37-38  
in nuclear medicine, 38, 56  
of radionuclides, 57-58  
of radiopharmaceuticals, 59  
saturation level of, 56
- Specific ionization (SI), 68, 69f, 71



- Specificity of receiver operating characteristic, 249
- SPECT. *See* Single photon emission computed tomography (SPECT).
- SPECT/CT, 4-5
- advantages of, 332-334, 356-357
  - applications of
    - clinical, 351-352, 353f
    - research, 353f, 354
  - attenuation correction in, 356-360
  - image segmentation in, 357
  - detectors in
    - clinical, 350-352
    - small-animal, 352-354
  - gamma cameras in, 350f, 351, 352f
  - sampling in, 349
  - scanners for
    - clinical, 350-352, 350f, 352f-353f
    - small-animal, 352-354, 353f
  - scatter correction in, 356-360
  - vs. SPECT, 351-352
- SPECT/MRI, 360-361
- Spectral blurring, 144, 148-151. *See also* Energy resolution.
- Spectrometry. *See* Pulse-height spectrometry.
- Spillover, 299
- Spills, safety measures for, 438
- Spontaneous fission, 43
- Spontaneous radioactive decay, 19
- SPRINT II system, 280-281, 282f
- Sr-85, as calibration standard, 165t
- Stable nuclides, 14-18, 16f-17f, 27, 28
- Standard deviation (SD), 128, 134, 135-136
- of gaussian spectral curve, 149
- Standards, measurement, 125. *See also* Calibration sources.
- Statistical analysis, 125-140. *See also* Measurements.
- applications of, 130-133
  - background effects, 131
  - counting measurement
    - differences, 130-131
  - counting rates, 130-133. *See also* Counting rates.
  - counting system comparisons, 132
  - effects of averaging, 130
  - estimating counting times, 132
  - minimum detectable activity, 131
  - optimal division of counting times, 133
  - chi square test in, 133-134, 134f
  - confidence intervals in, 127, 127t
  - constant multipliers in, 129
  - correlation coefficient in, 139-140
  - counting system comparison and, 132
  - dead time losses and, 171
  - frequency distributions in, 126, 127f, 128
- Statistical analysis (*Continued*)
- Gaussian distribution in, 127f, 128
  - linear regression in, 139-140
  - mean value in, 126, 127, 127t, 128, 135-137
  - measurement errors and
    - propagation of, 128-130
    - types of, 125-126
  - minimum detectable activity in, 131
  - nuclear counting statistics in, 126-128
  - outliers in, 138, 138t, 139f
  - percentage uncertainty in, 127, 129
  - Poisson distribution in, 126-128, 127f
  - products and ratios in, 129
  - standard deviation in, 128, 134, 135-136
  - of gaussian spectral curve, 149
  - statistical significance in, 130-131
  - sums and differences in, 129
  - tests of significance in, 130-131, 133, 135, 136f, 140
  - t*-test in, 135-137
- Statistical errors. *See* Measurement errors.
- Statistical noise, 243-247.
- See also* Contrast-to-noise ratio (CNR); Signal-to-noise ratio (SNR).
  - in PET image, data corrections and, 340, 341
  - in reconstructed image, 261, 263, 271, 273
  - scatter corrections and, 298
- Statistical (random) noise, 243
- contrast-to-noise ratio and, 243-244
- Statistical tests, 133-140
- chi square test, 133-134, 134f
  - outliers in, 138, 138t, 139f
  - t*-test, 135-137
- Steady state, 385-386, 386f
- Stopping power, linear, 68
- Streak artifacts, 262, 265f, 273
- Structured noise, 243
- Student *t*-test, 135-137
- Substates of atom, 9, 9f, 10, 12
- Substrates of enzymatic reactions, 385, 385f, 387
- Subtraction, image, 371, 372f
- Sulfur-35, 452
- Summation circuits, 184
- Surface dose, 409
- Surface rendering, 369-371
- Surgery, gamma probes for, 193f, 194
- Survey meters, 439-440
- for  $\beta$  particles, 166-167, 166f
  - Geiger-Müller counters in, 95-96, 95f, 439
  - ionization chamber, 89, 89f
  - energy response curve for, 90-91, 91f
  - quality checks of, 172
- Survey meters (*Continued*)
- surface contamination and, 166
  - windows of, 166
- Sv. *See* Sievert (Sv).
- S-value tables
- for F-18, 422t-423t
  - for I-131, 420t-421t
  - for Tc-99m, 418t-419t
- Synchrocyclotron, 48
- Syringes
- dose rates in contact with, 431-432
  - shielding for, 436-437, 436f
- System alignment, in SPECT, 302-303
- System resolution, 265-266
- of gamma camera, 210-211, 225, 227
  - measurement of, 229
  - in PET, 314-315
- System sensitivity, for gamma cameras, 231
- System volume sensitivity, 301-302
- Systematic errors, 125
- Système International (SI) units, 7, 32, 407, 408, 409, 429, 443
- T**
- TAC (time-activity curve). *See* Time-activity curve (TAC).
- Target nucleus, in neutron activation, 46, 47
- Target organs, 408, 409, 409f, 413-414, 415, 418t-423t
- TCT. *See* Transmission computed tomography (TCT).
- TDS rules. *See* Time, distance, shielding (TDS) rules.
- Technetium-99m
- advantages of, 50-51
  - calibration standard for, 164, 166, 189
  - carrier in sample of, 38
  - carrier-free, 38
  - characteristics of, 462
  - contaminants in, 53, 58, 190
  - decay factors for, 34, 34t
  - dosimetry of, internal, 416
  - energy resolution in detection of, 150, 151, 152f, 153f, 210, 211, 212, 231
  - gamma camera imaging with
    - collimator sensitivity in, 231
    - counting rate in, 230
    - energy resolution in, 150, 151, 152f, 153f, 210, 211, 212, 231
  - image distortion in, 217
  - intrinsic resolution in, 210, 211
  - spatial resolution in, 235
  - historical development of, 2, 4
  - mean dose per cumulated activity for, 415-416, 418t-419t
  - as metastable state, 15, 24
  - production of, 50-53, 51f, 51t
  - properties of, 58t

- Technetium-99m (*Continued*)  
 radiopharmaceuticals labeled with  
   dose estimates for, 479t  
   examples of, 5t, 379, 381t  
   from kits, 60, 60t  
 RBCs labeled with, 392  
 renal studies with, 379  
 for sentinel node detection, 192-193  
 SPECT imaging with  
   attenuation in, 287, 287f, 288f, 289f, 290, 290f, 291t  
   clinical applications of, 303f, 304, 304f, 305, 305f, 306  
   performance measurement in, 301  
   scattering in, 297, 298, 298f  
   transmission scan and, 294, 296, 296f  
   in syringes, dose rates with, 431-432  
 Tenth-value thickness (TVT), 82, 82t, 437  
 Tetrofosmin, <sup>99m</sup>Tc-labeled, 5t, 304  
 Thallium-201, 58t, 303, 304, 474-475  
 Thallium-201 chloride, 5t, 394, 479t  
 Thallium-activated cesium iodide [CsI(Tl)], 100, 101t  
   in compact gamma camera, 207  
   in intraoperative gamma probe, 193, 193f  
 Thallium-activated sodium iodide [NaI(Tl)]. *See* NaI(Tl)  
   detectors.  
 Thermal emission noise, 184  
 Thermal neutrons, 43-44  
 Thermoluminescent dosimeters (TLDs), 440, 440f  
 Thompson criteria, 138  
 Three-dimensional data  
   acquisition  
     in PET, 332, 333f, 334-335  
     voxels in, 285, 339-340, 364, 367  
 Three-dimensional iterative reconstruction, 276  
 Three-dimensional PET reconstruction, 275-276, 276f  
 Threshold dose, 427  
 Through-hole detectors, 180, 180f-181f  
 Thyroid, uptake of iodine in, 192, 192f  
 Time, distance, shielding (TDS) rules, 436-437  
 Time constants  
   amplifier, 110-113, 110f, 111f, 114f  
   preamplifier, 107-110, 108f  
   rate meter, 120  
 Time stamp, 307  
 Time-activity curve (TAC)  
   cumulated activity and, 409, 410, 410f  
   image processing and, 373, 374f  
   kinetic modeling and, 379-380, 385f, 392, 396f, 401  
 Time-of-flight PET, 309-310, 310f  
 Timers, 119-120, 119f  
 Time-to-amplitude converters, 118-119, 119f  
 Timing resolution, 307-308  
 Timing walks, 115  
 Tissue. *See also* Organs.  
   attenuation coefficient in, 287, 287f, 293  
   transmission scan and, 294, 337  
   extraction of tracer by, 386-390, 387f, 388f, 389f  
   *f* factor for, 430, 430f  
   positron ranges in, 314  
 Tissue compartments. *See* Compartmental models.  
 Tissue response curves, 391  
 Tissue weighting factors, 417, 425t  
 TLDs. *See* Thermoluminescent dosimeters (TLDs).  
 Tomographic imaging, 253-278. *See also* Positron emission tomography (PET); Single photon emission computed tomography (SPECT).  
   advantages of, 253, 269  
   basic concepts of, 254-256, 254f, 255f, 256f  
   contrast in, 241-242, 243f, 269  
     in PET, 241-242, 253, 336, 337, 346  
     in SPECT, 241-242, 243f, 297, 299  
   coordinate systems in, 255-256, 256f  
   digital image format for, 364. *See also* Digital image processing.  
   emission, 253  
   historical development of, 4, 253  
   image processing in. *See* Digital image processing.  
   image quality in. *See also* Sampling; Spatial resolution:  
     tomographic reconstruction and.  
     consistency requirements and, 266, 266f  
     with FT and FBP, 263, 264f, 265-270, 265f, 266f, 267f  
     noise and, 253, 266-270, 267f  
   image reconstruction in. *See* Reconstruction tomography.  
   limited-angle, 266  
   for low-contrast imaging, 241-242  
   mathematical techniques in. *See also* Fourier transform (FT).  
     with cone-beam collimator, 274-275, 274f  
     direct Fourier transform as, 258-260, 259f  
     with fan-beam collimator, 273-274, 274f-275f  
   filtered backprojection as. *See* Filtered backprojection (FBP).  
   iterative reconstruction as. *See* Iterative reconstruction.  
   for multiple slices, 262-263  
   for PET, 253, 336, 337  
 Tomographic imaging (*Continued*)  
   with pinhole collimator, 274-275  
   simple backprojection as, 256-258, 257f, 258f  
   in multimodality  
     instrumentation, 4-5  
   overview of, 254-256  
   terminology of, 254-256  
   transmission, 253  
   types of, 253  
 Total-body dose, 417. *See also* Whole-body imaging.  
 Total-spectrum counting rate, 170  
 Townsend, David, 354  
 Townsend avalanche, 91  
 TPF. *See* True-positive fraction (TPF).  
 Tracer kinetic modeling, 379-405  
   basic concepts of, 379-380, 380f  
   blood flow measurement and, 392-396. *See also* Blood flow: measurement of.  
   cardiac imaging and, 392  
   compartment models for, 390-392, 390f-391f  
   compartments in, 380-386  
     dilution principle and, 382-383  
     distribution volume of, 382-383, 384f  
     flux between, 383-384  
     nondisplaceable, 384, 402f  
     open vs. closed, 382-383  
     partition coefficient and, 383  
   of complex systems, 402  
   distribution volume in, 382-383  
   dynamic imaging and, 392-403  
   enzyme kinetics and, 396-401  
   equilibrium models in, 386  
   extraction in, 386-388, 387f, 388f, 389f, 390-391, 390f  
   first-order kinetics in, 384-385  
   glucose metabolism and, 396-401  
   rate constants in, 384-385, 384f, 385f, 390-391, 390f, 396  
   receptor ligand assays and, 401-403, 402f, 404f  
   steady state in, 385-386, 386f  
   time-activity curves in, 373, 374f, 379-380, 410, 410f  
   tracer characteristics in, 380-382  
   tracer delivery and, 386-390  
     blood flow and, 386-387  
     clearance and, 388, 389f  
     extraction and, 386-388  
     Fick principle and, 387  
     Renkin-Crone model for, 387-388, 388f-389f, 390-391  
     transport and, 389-390  
 Tracer studies. *See also* Radiopharmaceuticals; Tracer kinetic modeling.  
   of blood flow. *See* Blood flow.  
   of cardiac function. *See* Cardiac studies.

Tracer studies (*Continued*)  
 of enzyme kinetics, 396-401, 397f, 398f, 401f  
 gamma camera for, 197  
 historical, 2  
 of receptors, 401-402, 402f  
 Tracers. *See* Radionuclides;  
 Radiopharmaceuticals; Tracer  
 kinetic modeling.  
 Transaxial direction, 254-255  
 Transaxial resolution, 301  
 Transaxial sections, orientation of,  
 369, 370f  
 Transient equilibrium, 41, 41f  
 Transistors, field-effect, 109  
 Transit time, mean, 380, 380f,  
 384  
 Transition energy ( $Q$ ), 19, 20, 20f,  
 21, 21f, 22  
 Transmission computed  
 tomography (TCT), 253. *See*  
*also* Tomographic imaging.  
 Transmission curves  
 for  $\alpha$  particles, 70, 70f  
 for  $\beta$  particles and electrons,  
 71-72, 73f  
 for photons, 84  
 Transmission factors, 83  
 Transmission scans  
 in PET attenuation correction  
 postinjection, 338-339  
 with SPECT, 294-296,  
 295f-297f  
 Transmutation of elements, 20, 21,  
 24, 25, 27  
 Transport  
 active, 389  
 passive, 389-390  
 carrier-mediated diffusion and,  
 389  
 Transverse direction, 254-255  
 Transverse sections, orientation of,  
 369, 370f  
 Trapping methods for blood flow  
 measurement, 393-394  
 Triple-head gamma camera,  
 206-207  
 True coincidences, 322-323, 322f  
 True color display, 367  
 True-positive fraction (TPF), 249,  
 250f  
 Truncation artifacts, 359, 359f  
 $t$ -test, 135-137  
 Tumor imaging  
 FDG-PET in, 341  
 gamma-ray probes in, 192-193  
 PET/CT in, 355-356, 356f  
 SPECT in, 305-306  
 Tungsten septa, 323  
 Turnover time, 384  
 TVT. *See* Tenth-value thickness  
 (TVT).  
 Two-energy window analysis,  
 184  
 Two-source method, 171, 171f

## U

Ultraviolet (UV) photons  
 in Geiger-Müller counter, 92, 94  
 in scintillation detector, 99-100

Undersampling, 263, 264f, 484,  
 485f, 486  
 in annihilation coincidence  
 detection, 318  
 with iterative algorithms, 273  
 pixel size and, 366  
 Unidirectional extraction fraction,  
 387, 388, 388f, 389f  
 Unified atomic mass unit (u), 7  
 Uniformity measurements for  
 gamma cameras, 229-230  
 Unipolar pulse, 112, 113  
 Units of measure, 7-8  
 for radiation, advisory body for,  
 433  
 for radiation dose, 407  
 SI, 7, 32  
 Universal decay curve, 35, 35f  
 Unrestricted areas, 431-432  
 Upper-level discriminator, 113,  
 114f  
 Uptake half-time, 410-411  
 Uptake of tracer, 59, 387, 410-411.  
*See also* Extraction.  
 Uranium, in nuclear reactors,  
 43-44  
 Urine samples, counting systems  
 for, 105, 173, 182  
 Useful field-of-view (UFOV), 217,  
 229, 230, 231  
 in PET, 319, 320, 320f, 321, 323

## V

Valid events, 204  
 Variance, 126-127  
 Ventricular ejection fraction,  
 calculation of,  $^{99m}\text{Tc}$ -labeled red  
 cells for, 392, 392f  
 Vials, counting, 184-185  
 Voltage, saturation, 87-88, 88f  
 Voltage response curve, for  
 ionization chambers, 87-88,  
 88f, 91, 92f  
 in Geiger-Müller counters, 94f  
 in proportional counters, 92f  
 Voltage-sensitive preamplifiers,  
 107-108, 109f  
 Volume, sample. *See* Sample  
 volume.  
 Volume of interest, 373  
 Volume sensitivity in SPECT,  
 301-302  
 Voxels, 285, 339-340, 364, 367

## W

Waste disposal, 439  
 Water, radioactivity in, regulation  
 of, 431, 432  
 Wavelength, 8  
 Waveshifters, 89-90  
 Weight, atomic, 13  
 Weighting factors, 408, 408t, 417,  
 424, 428, 429t, 435  
 Weiss, S., 2  
 Well counters. *See* NaI(Tl) well  
 counters.  
 White blood cells, labeling of, 5t  
 Whole-body counters, 194  
 Whole-body dose, 417

Whole-body imaging  
 with gamma camera, 207f  
 with PET, 335, 340, 340f  
 Wilkinson converters, 117-118,  
 117f  
 Window fractions, dead times and,  
 170-171, 213, 213f  
 Window width, 113  
 Windowing, 369  
 Windows  
 coincidence timing, 121, 307  
 entrance, 98, 98f, 101-102, 104  
 thickness of, 166-167  
 for gamma cameras, 201  
 optical, 101-102  
 scatter, 298, 298f  
 of survey meters, 166  
 Wipe testing, 441  
 Wrenn, F.R., 2

## X

X rays, 8-9, 8f. *See also* Photons.  
 characteristic. *See* Characteristic  
 x rays.  
 Compton scattering of, 75, 75t  
 detection of. *See* Radiation  
 detectors.  
 discovery of, 2  
 in electromagnetic spectrum, 8,  
 8f  
 health physics and, 429, 434-435  
 interactions with matter, 74-78  
 passage through matter, 74-78  
 pulse-height spectrum and,  
 142-145  
 radiobiologic effects of, 78  
 scattering of. *See* Scattered  
 radiation.  
 Xenon-133  
 blood flow measurement with,  
 395, 396  
 characteristics of, 472  
 decay scheme of, 21, 22, 22f, 472  
 safe handling of, 433t, 433  
 Xenon, nuclear energy-level  
 diagram for, 15, 15f  
 X-ray computed tomography, 253,  
 346-350. *See also* Hybrid  
 imaging systems.  
 coherent scattering in, 77  
 in co-registered imaging,  
 375-376, 377f  
 image quality in, 263-270  
 with PET. *See* PET/CT.  
 reconstruction in, 348-350, 349f  
 scanners in, 348, 348f  
 scattered radiation in, 349  
 spatial resolution in, 349  
 with SPECT. *See* SPECT/CT.  
 x-ray detectors in, 347-348, 348f  
 x-ray tubes in, 346-347, 346f-347f  
 X-ray detectors, 347-348, 348f  
 X-ray tubes, 346-347, 346f-347f,  
 355

## Z

Z. *See* Atomic number (Z).  
 Zero padding, 489  
 Zero-crossover timing, 115-116