Appendix A Glossary of Nuclear Terms

absorber: Any material that stops ionizing radiation. Lead, concrete, and steel attenuate gamma rays. A thin sheet of paper or metal will stop or absorb alpha particles and most beta particles.

accelerator: Device used to increase the energy of particles, which then collide with other particles. Major types are linear accelerators and circular accelerators. The name refers to the path taken by the accelerated particle.

activity: The rate of radioactive decay.

alpha particle (alpha radiation, alpha ray): A ^{4}He nucleus. It is made up of two neutrons and two protons. It is the least penetrating of the three common forms of radiation, being stopped by a thin sheet of paper. It is not dangerous to living things unless the alpha-emitting substance is inhaled or ingested or comes into contact with the lens of the eye.

annihilation: Annihilation of particles is the disappearance of the mass energy of a particle and its corresponding antiparticle, and its appearance as another sort of energy (possibly including a spray of particles of total quantum number zero for each of the additive quantum numbers).

antineutrino: Antiparticle to the neutrino. See antiparticles.

antiparticle: Particle having the same mass, spin, isospin as a particle, but having all additive quantum numbers opposite to those of its respective particle. Antiparticles have the opposite charge of its corresponding particle. Antibaryons are antiparticles to baryons, antileptons are antiparticles to leptons, and antiquarks are antiparticles to quarks. The antiparticle for a particular particle, for example a neutrino, is denoted an antineutrino.

asymptotic freedom: Quark-quark interactions weaken as the energy gets higher, or, equivalently, as the quarks approach one another.

atom: A particle of matter indivisible by chemical means. It is the fundamental building block of molecules. It consists of a positively charged nucleus and orbiting electrons. The number of electrons is the same as the number of protons in the nucleus.

atomic mass (sometimes mistakenly called atomic weight): The mass of a neutral atom. Its value in atomic mass units (u) is approximately equal to the sum of the number of protons and neutrons in the nucleus of the atom.

atomic mass number: *A*, the total number of nucleons (protons and neutrons) found in a nucleus.

atomic number: *Z*, the total number of protons found in a nucleus.

atomic mass unit (amu or u): Unit of mass defined by the convention that the atom ^{12}C has a mass of exactly 12 u; the mass of 1 u is 1.67×10^{-27} kg.

background radiation: The radiation found in the natural environment originating primarily from the naturally radioactive elements of Earth and from cosmic rays. The term may also mean radiation extraneous to an experiment.

baryon: A massive composite hadron (made of three quarks) such as the proton or the neutron.

baryon number: Quantum number characteristic of baryons. Each baryon has a value of +1, while each anti-baryon has a value of -1.

becquerel (Bq): Unit of activity in the International System—one disintegration per second; 1 Bq = 27 pCi.

beta particle (beta radiation, beta ray): An electron of either positive charge (e^+ or β^+) or negative charge (e, e^- or β^-) emitted by an atomic nucleus or neutron in the process of a transformation. Beta particles are more penetrating than alpha particles but less than gamma rays or x-rays. Electron capture is a form of beta decay.

Big Bang: Beginning of the universe; a transition from conditions of unimaginable density and temperature to conditions of lower density and temperature.

blackbody: An object that is a perfect emitter and absorber of radiation.

blackbody radiation: Radiation emitted by a blackbody (the intensity depends on temperature).

black hole: An object so dense that light cannot escape from it.

boson: A particle having spin that is an integer multiple of $\hbar$.

Cherenkov radiation: Light emitted by particles that move through a medium in which the speed of light is slower than the speed of the particles.

conservation law: A relation asserting that a specific quantity is conserved. For example, conservation of energy, conservation of momentum, conservation of electron number. Conservation laws are connected to symmetries through Noether's theorem.

cyclotron: Circular accelerator in which the particle is bent in traveling through a magnetic field, and an oscillating potential difference causes the particles to gain energy.

cyclotron frequency: Frequency at which the electric field is switched in order to accelerate the particles in the cyclotron. The frequency is related to the mass and charge of the particle to be accelerated.

curie (Ci): The original unit used to describe the intensity of radioactivity in a sample of material. One curie equals thirty-seven billion disintegrations per second, or approximately the radioactivity of one gram of radium. This unit is no longer recognized as part of the International System of units. The becquerel has replaced it.

daughter: A nuclide formed by the radioactive decay of a different (parent) nuclide.

decay (radioactive): The change of one radioactive nuclide into a different nuclide by the spontaneous emission of radiation such as alpha, beta, or gamma rays, or by electron capture. The end product is a less energetic, more stable nucleus. Each decay process has a definite half-life.

decay rate: The ratio of activity to the number of radioactive atoms of a particular species.

decay time: The time required for a quantity to fall to $1/e$ times the original value.

dees: Regions of space in a cyclotron shielded from electric field in which the magnetic field causes the particles to bend in a semicircle.

density: The ratio of an object's mass to its volume.

detector: A device or series of devices used to measure nuclear particles and radiations.

dose: A general term denoting the effect of absorption of a quantity of radiation or energy absorbed.

electric dipole moment: The product of charge and distance of separation for an electric dipole.

electromagnetic radiation: Radiation consisting of electric and magnetic fields that travel at the speed of light. Examples**:** light, radio waves, gamma rays, x-rays.

electron: An elementary particle with a unit electrical charge and a mass 1/1837 that of the proton. Electrons surround an atom's positively charged nucleus and determine that atom's chemical properties.

electron-volt (eV): Energy unit used as the basis of measurement for atomic (eV), electronic (keV), nuclear (MeV), and subnuclear processes (GeV or TeV). One electron-volt is equal to the amount of energy gained by an electron dropping through a potential difference of one volt, which is 1.6×10^{-19} joules.

electron capture: A radioactive decay process in which an orbital electron is captured by and merges with the nucleus. The mass number is unchanged, but the atomic number is decreased by one.

electroweak interaction: A theory that unifies the electromagnetic and weak interactions.

excited state: The state of an atom or nucleus when it possesses more than its normal energy. Typically, the excess energy is released as a gamma ray.

fermion: A particle having a spin that is an odd integer multiple of $\hbar/2$.

fissile nucleus: A nucleus that may fission after collision with a thermal (slow) neutron or that fissions spontaneously (by itself).

fission: The splitting of a heavy nucleus into two roughly equal parts (which are nuclei of lower-mass elements), accompanied by the release of a relatively large amount of energy in the form of kinetic energy of the two parts and in the form of emission of neutrons and gamma rays.

fission products: Nuclei formed by the fission of higher mass elements. They are of medium atomic mass and almost all are radioactive. Examples: ^{90}Sr, ^{137}Ce.

fusion: A process whereby low mass nuclei combine to form a more massive nucleus plus one or move massive particles.

gamma ray: A highly penetrating type of nuclear radiation, similar to x-radiation, except that it comes from within the nucleus of an atom, and, in general, has a shorter wavelength.

gauge boson: Particle mediating an interaction. By exchange of the gauge particle, the interaction between two particles is accomplished.

Geiger counter: A Geiger-Müller detector and measuring instrument. It consists of a gas-filled tube that discharges electrically when ionizing radiation passes through it and a device that records the events.

gluon: A gauge particle mediating the color strong interaction.

gray (Gy): Unit of absorbed dose due to any type of radiation. An exposure to 1 gray results from radiation depositing one joule per kilogram of animal tissue or any other material.

hadron: A strongly interacting particle.

half-life: The time in which half the (large number of) atoms of a particular radioactive nuclide disintegrate. The half-life is a characteristic property of each radioactive isotope.

homolog (or homologs): Elements in the same periodic table group that tend to exhibit similar, but not identical, chemical properties.

hormesis: Controversial theory that argues that there is a benefit to health, or decrease in biological damage from radiation as dose in increased (valid only for very small doses).

Hubble Constant: Ratio of outward speed of galaxies to their distances from Earth.

induced radioactivity: Radioactivity that is created by bombarding a substance with neutrons in a reactor or with charged particles produced by particle accelerators.

infrared radiation: Electromagnetic radiation of longer wavelength than visible light.

ion: An atomic particle that is electrically charged, either negatively or positively.

ionizing radiation: Radiation that is capable of producing ions either directly or indirectly.

irradiate: To expose to some form of radiation.

isomer: Nuclides with the same number of neutrons and protons in different states of excitation.

isomeric transition: A relatively long-lived radioactive decay in which a nucleus goes from a higher to a lower energy state. The mass number and the atomic number are unchanged.

isotope: Isotopes of a given element have the same atomic number (same number of protons in their nuclei) but different mass numbers (different number of neutrons in their nuclei). ^{238}U and ^{235}U are isotopes of uranium.

joule (J): Unit of energy, equivalent to the work done in lifting a one-newton weight a distance of one meter.

K-capture: The capture by an atom's nucleus of an electron from the innermost electron orbital (K-shell) surrounding the nucleus.

kelvin (K): Unit of temperature equal in size to the Celsius degree, but with the zero set by the absolute zero of temperature, -273.15°C. Ice freezes at 273 K, room temperature is about 293 K, and water boils at 373 K, at sea level. human body temperature is 310 K.

keV: One thousand electron volts.

lepton: A particle (such as the electron or neutrino) that is not subject to strong interactions.

lepton number: Additive quantum number defining leptons; the three lepton numbers are electron number, muon number, and tau number. These numbers remain the same in all reactions.

lifetime: The mean life of a particle or radioactive nucleus. This is equivalent to the decay time.

linac: Another name for a linear accelerator.

linear accelerator: A particle accelerator that follows a straight line.

mass energy: Energy a particle has by virtue of its mass (given by m times c^2).

mass number: The total number of protons and neutrons in the nucleus**:** $A=Z+N$. This is also the total nucleon number of the nucleus.

meson: A particle (such as the pion) made of quark-antiquark pairs.

MeV: One million electron volts.

microwaves: Electromagnetic radiation with wavelength intermediate between radio wave and infrared radiation.

multiwire proportional counter: Particle detector using changes in the current in wires due to the passage of ionizing particles nearby.

muon: A charged lepton about 200 times more massive than an electron.

muon number: Additive quantum number characterizing muons and muon neutrinos.

neutrino: An electrically neutral particle with negligible mass. It is produced in processes such as beta decay and reactions that involve the weak force.

neutron: One of the basic particles that make up a nucleus. A neutron and a proton have about the same mass, but the neutron has no electrical charge.

neutron number: The total number of neutrons in the nucleus, N.

nuclear binding energy: The energy that free nucleons give up in order to be bound inside a nucleus.

nuclear reactor: A device in which a fission chain reaction can be initiated, maintained, and controlled. Its essential components are fissionable fuel, moderator, shielding, control rods, and coolant.

nucleon: A constituent of the nucleus; that is, a proton or a neutron.

nucleus: The core of the atom, where most of its mass and all of its positive charge is concentrated. Except for ^{1}H, the nucleus consists of a combination of protons and neutrons.

nuclide: Any species of atom that exists for a measurable length of time. Its atomic mass, atomic number, and energy state can distinguish a nuclide.

parent: A radionuclide that decays to another nuclide.

photon: A packet of electromagnetic energy. Photons have momentum and energy, but no rest mass or electrical charge.

photomultiplier: Commonly used device for detecting photons by converting them to an electrical signal.

pion: The least massive known spin-0 meson. The three charge states of the pion (negative, neutral and positive) are involved in the long-range force between the nucleons.

proton: One of the basic particles that makes up an atom. The proton is found in the nucleus and has a positive electrical charge equal to the negative charge of an electron and a mass similar to that of a neutron**:** a hydrogen nucleus.

proton number: The total number of protons in the nucleus, Z.

QCD: Quantum chromodynamics, the gauge theory describing the color strong interaction.

QED: Quantum electrodynamics, the gauge theory describing electromagnetism.

quark: A strongly interacting fermion that is a building block of hadronic matter. Quarks come in six flavors: up, down, charm, strange, top, and bottom.

rad (Radiation Absorbed Dose): A former unit of an absorbed dose of ionizing radiation. One rad is equal to the absorption of radiation energy per gram of matter. It has been replaced by the gray (see above).

radioactive dating: A technique for estimating the age of an object by measuring the amounts of various radioisotopes in it.

radioactive waste: Materials that are radioactive and for which there is no further use.

radioactivity: The spontaneous decay or disintegration of an unstable atomic nucleus accompanied by the emission of radiation.

radioisotope: A radioactive isotope. A common term for a radionuclide.

radionuclide: A radioactive nuclide. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation.

rem (röntgen equivalent, man): A measure of dose deposited in body tissue, averaged over the body. One rem is approximately the dose from any radiation corresponding to exposure to one röntgen of γ radiation. The rem is no longer accepted for use with the International System. One rem is equivalent to 0.01 sievert.

residual strong force: Force between composite objects (made of quarks) due to the remaining effect of the color force on colorless objects. These forces are much weaker than the strong color force.

röntgen or **roentgen (R):** Unit of exposure measuring the ionizing ability of γ radiation; one röntgen produces one electric charge (1.6×10^{-19} C) per 10^6 m^3 of dry air at 0°C and atmospheric pressure. This corresponds to an energy loss of 0.0877 joule per kilogram in air. The röntgen is no longer accepted for use with the International System.

scaler: An electronic instrument for counting radiation induced pulses from radiation detectors such as a Geiger-Müller tube.

scintillation counter: An instrument that detects and measures gamma radiation by counting the light flashes (scintillations) induced by the radiation.

scintillator: Material that emits light when particles traverse it.

secular equilibrium: A state of parent-daughter equilibrium that is achieved when the half-life of the parent is much longer than the half-life of the daughter. In this case, if the two are not separated, the daughter will eventually decay at the same rate at which it is being produced. At this point, both parent and daughter will decay at the same rate until the parent is essentially exhausted.

shielding: A protective barrier, usually a dense material that reduces the passage of radiation from radioactive materials to the surroundings by absorbing it.

sievert (Sv): A measure of dose (technically, dose equivalent) deposited in body tissue, averaged over the body. Such a dose would be caused by an exposure imparted by ionizing x-ray or gamma radiation undergoing an energy loss of 1 joule per kilogram of body tissue (1 gray). One sievert is equivalent to 100 rem.

source: A radioactive material that produces radiation for experimental or industrial use.

stable: Non-radioactive.

Standard Model: Gauge theory encompassing the electroweak and strong interactions.

strong interaction: The interaction due to exchange of color. Also called strong force.

symmetry: Invariance of equations of motion under changes in condition.

thermal energy: Random kinetic energy possessed by objects in a material at finite temperature.

tracer: A small amount of radioactive isotope introduced into a system in order to follow the behavior of some component of that system.

transmutation: The transformation of one element into another by a nuclear reaction.

ultraviolet radiation: Electromagnetic radiation having wavelengths between the visible part of the spectrum and x-rays.

Van de Graaff accelerator: Device using a high voltage terminal to accelerate charged particles.

weak interaction: The interaction responsible for weak decays of particles, mediated by the exchange of $W^{\pm}$ and Z^0 gauge bosons.

x-radiation: Electromagnetic radiation usually produced in transitions of the inner electrons of atoms. The wavelength is between ultraviolet and gamma rays.

x-ray: Electromagnetic radiation with wavelengths between ultraviolet and gamma rays.