# Glossary

***ab-initio* (computation):** computation carried out on the basis of theoretical data, and intended to be fully predictive.

**absorption:** the process whereby the intensity of a radiation decreases as it passes through a medium.

**actinides:** natural, and/or artificial **radioelements** (belonging to the group of **rare earths**), of atomic number (i.e. the number of **protons** in the **nucleus**) ranging from 89 to 103 (see also: **major actinides**, **minor actinides**).

**activation:** the process whereby certain initially stable **nuclides**, particularly in reactor and **fuel element** structural materials, are made **radioactive**, through **neutron** bombardment (**neutron activation**), or bombardment by other particles.

**activity:** the number of **decays** per unit time within a **radionuclide**, or a mixture of radionuclides, expressed in **becquerels** (**Bq**). **Specific activity** is expressed in becquerels per gram (Bq/g). **High activity** may reach several billion becquerels per gram.

**ADS (accelerator-driven system):** a **hybrid** nuclear system, coupling a **subcritical** reactor core and a high-energy **proton** accelerator, this yielding, through **spallation** reactions inside a target, the complement of **neutrons** required to sustain the **chain reaction**, ensuring the **transmutation** of nuclear waste, or power generation.

**algorithm:** a sequence of logical–mathematical operations required for the carrying out of a computation task.

**alloy:** a metallic material, obtained through the incorporation of one or more elements into a parent metal.

**alpha (emission):** see **radioactivity**.

**amorphization:** the process bringing to a state characterized by an absence of order in the arrangement of particles of matter, as opposed to the **crystalline** state.

**anisotropy**: the variation in properties exhibited, depending on direction; this is quantified by the **degree of anisotropy**.

**assembly** (fuel)**:** a structure made up of **fuel elements**, loaded into a nuclear reactor as a single unit.

**atom:** the basic constituent of normal matter, comprising a **nucleus** (made up of **protons** and **neutrons**) around which **electrons** orbit.

**backup pressure:** in a gas-cooled reactor, the equilibrium pressure that ultimately obtains, between the **primary circuit** and the guard containment (second pressure barrier) inside which it is confined, in the event of an accidental primary circuit failure, resulting initially in a fall in pressure inside that circuit, and increasing pressure in the enclosure, which contains the gas it already holds, together with that escaping from the primary circuit.

**bar:** a unit of pressure: 1 bar = $10^5$ Pa (the **pascal** is the scientific, legal unit).

**barn:** the unit used to measure **cross-sections** (1 barn = $10^{-24}$ $cm^2$).

**barriers:** in a nuclear reactor, the ensemble of physical components serving to isolate the **radionuclides** in the **fuel** from the environment.

**beta:** a form of radiation consisting of **electrons** (beta$^-$ **radioactivity)** or positrons (beta$^+$ radioactivity).

**beta-minus decay:** see **radioactivity**.

**biomass:** the mass of living matter, whether vegetable (to a proportion of over 99%) or animal, present on the face of the Earth.

**breach:** a breach, or failure occurring in part of a reactor circuit, more particularly in the primary circuit.

**breeding:** a process allowing, in a nuclear reactor, **fissile** material to be generated, even as the reactor consumes such material (see also: **positive breeding gain**, **zero breeding gain**).

**breeding gain:** this expresses the difference, positive or negative, between the production, and consumption of **fissile atoms**. With respect to **plutonium**, for instance, this is defined as the ratio (production – consumption) of $^{239}$Pu equivalent/number of fissions. The **internal breeding gain** is only concerned with the fuel regions inside the core.

**burnup** (or **burnup fraction**)**:** a term used (improperly) to refer to **specific burnup**, i.e. the total thermal energy released per unit mass of **fissile** material in a nuclear **fuel**, from the time it is charged into the reactor, to discharge, expressed in megawatts–day per tonne (MW · d/t), or gigawatts–day per tonne (GW · d/t). This corresponds to the percentage, expressed in at % (**% FIMA**), of **heavy nuclei** that have undergone **fission**, over a given time interval, referred to the number of nuclei initially present (tiHM). The relationship between burnup and specific burnup stands, in practice, as 1 at % = 10 GW · d/tiHM. **Discharge burnup** is the value for which the **fuel assembly**, after several **irradiation** cycles, must be finally discharged, for a certain **isotopic** proportion of **uranium** 235 in the **depleted uranium** (currently, about 0.25%).

**carbide** (actinide)**:** a chemical form used for **fuel**, in which the **fissile element** is combined with carbon, rather than oxygen as in **oxide** fuels.

**cascade** (of atom displacements)**:** a sequence of **atom** ejections, away from their equilibrium sites in the **crystal** structure of a material, subsequent to a collision with an incoming particle. If the energy yielded by the latter is close to the *threshold displacement energy*, a single atom will be expelled, leaving a defect known as a *Frenkel pair*. If the energy imparted to the first atom impacted is much higher than this threshold, a displacement cascade occurs, the ejected atoms being endowed with sufficient energy to dislodge further atoms.

**Castaing microprobe:** a probe used for a chemical analysis method (electron-probe microanalysis [EPMA]), invented by Raimond Castaing in 1951; the method involves bombarding a sample region, having a diameter of about 1 **micron**, with a focused **electron** beam, and analyzing the X-ray spectrum emitted in response to that excitation.

**ceramic:** an inorganic, nonmetallic material featuring a **crystal** structure exhibiting a regular, periodic **atomic** arrangement, and, in some cases, **ionic** or **covalent** bonds.

**chain reaction:** a sequence of nuclear **fissions**, in the course of which the **neutrons** released cause further fissions, which in turn yield further neutrons causing further fissions, and so on.

**clad, cladding:** an impervious envelope, encasing the **fuel** material, having the purpose of containing **radioactive** materials, and ensuring fuel isolation and mechanical strength inside a reactor core.

**cogeneration:** the use of thermal energy from a boiler (to wit, a nuclear reactor) for the purposes of several applications, e.g. for the simultaneous production of electricity, and heat.

**composite:** a material formed by assembly of a number of materials, exhibiting properties the latter do not exhibit separately. It may comprise a **fiber** skeleton (*reinforcement*) bearing mechanical loads, and a coating **matrix**.

**computation code:** software representing the expression of the numerical **model** for a system, or process.

**computation software:** the drawing up into a computer **code**, in the form of mathematical expressions, of the **model** for a system, or process.

**convection:** the ensemble of motions generated inside a fluid, owing to differences in density, and temperature at various points. **Natural convection** is the automatic transfer of heat through such circulation; **forced convection** involves the use of mechanical means.

# Glossary

**conversion factor:** in a nuclear reactor, the ratio, over a given time interval, of the number of **fissile nuclei** generated, over the number of fissile nuclei destroyed. A reactor exhibits **zero breeding gain** when this factor is equal to 1, **positive breeding gain** when it is higher than 1. This factor may be broken down into an **internal conversion factor**, only taking into account those conversions occurring within the core, and an external conversion factor, taking into account only those occurring in the **fertile** blankets. This term may also be used to specify the ability to use **uranium** 238, by way of its conversion into **plutonium**.

**conversion rate:** see **conversion factor**.

**conversion ratio:** see **conversion factor**.

**coolant:** a heat-transfer fluid, used for the purposes of heat removal from a nuclear reactor core.

**core meltdown:** an accident in which nuclear **fuel** is brought to a sufficiently high temperature for it to melt, and meld into a corrosive magma (the **corium**), at the bottom of the reactor vessel.

**corium:** a mixture of materials, yielded by the accidental meltdown of the core, and adjacent structures, inside the vessel of a nuclear reactor.

**creep:** the evolution over time of the plastic deformation of a material, under the effect of a mechanical **stress**, acting over an extended interval. The term **thermal creep**, as opposed to **irradiation creep**, refers to that component of creep that is due solely to the load applied, irrespective of any **irradiation**.

**critical mockup:** an experimental reactor, with near-zero output power, representative however in terms of **neutronics**, and **criticality**.

**criticality:** the state of a medium bearing **fissile** materials, within which a nuclear **chain reaction** is sustained, at a constant level. A mass of material is termed **critical** when the number of **neutrons** released by **fission** processes inside it is equal to the number of neutrons disappearing through **absorption,** and **leakage**. **Recriticality** is the return to a critical condition of a fissile medium that had moved away from it.

**criticality or power excursion:** a rapid change in the number of **fissions** occurring in a **fissile** medium, resulting in a very swift, temporary rise in a reactor's power.

**cross-section:** the measure of the probability of interaction between incident particles (e.g. **neutrons**) and a target **nucleus** (e.g. **uranium** nuclei); this is expressed in **barns**. For neutron-induced nuclear reactions, a distinction is made between **absorption** or **capture cross-section**, **fission cross-section**, and **elastic scattering cross-section**.

**crystal:** an assembly of **atoms**, **ions**, or **molecules** arrayed in regular, periodic fashion across all three space directions.

**cycle (fuel):** the ensemble of operations to which nuclear fuel is subjected, from ore extraction to **spent fuel reprocessing**, if required, and storage, or disposal of the waste, after use, possibly also involving in-reactor **recycling**. The cycle is "**closed**" when the spent fuel is reprocessed for recycling purposes, "**open**" otherwise.

**damage (rate):** a measure of the degradation of a metal, expressed in **dpa**.

**decay:** the transformation of an unstable **nucleus** into a stable, or unstable nucleus, whereby the number, and nature of **neutrons**, or **protons** (the constituents of the **atomic** nucleus) are altered.

**decay heat** (or **residual power**)**:** the thermal power released by a shutdown nuclear reactor, or by a **fuel assembly**. This is mainly generated by residual **fission** processes, the **decay** of **actinides**, and of **fission** and **activation products** held inside the fuel and structural materials. At the time of shutdown, residual power levels stand at a few percent of *nominal power*, falling off swiftly thereafter.

**delayed neutron fraction:** the ratio, expressed in **pcm**, of the average number of **delayed neutrons**, over the average total number of neutrons (**prompt**, and delayed), yielded by **fission**.

**delayed neutrons: neutrons** released by **fission** fragments, with a delay, on average, of a few seconds after fission has occurred. Accounting for less than 1% of neutrons released, they ultimately allow reactors to be controlled.

**depleted uranium (DU): uranium** having a content in **isotope** 235 lower than its natural level (0.72% by mass). This is mainly obtained, on the one hand, as the byproduct of an **enrichment** operation (with around 0.3% $^{235}$U), and, on the other hand, as a byproduct (1% $^{235}$U) of **spent fuel reprocessing** operations.

**deuterium:** one of the two "heavy" **isotopes** of **hydrogen**; its **nucleus** comprises one **proton**, and one **neutron**.

**dispersion:** a distribution of small particles, mixed with a homogeneous medium.

**dollar:** a unit of **reactivity**. The dollar (**$**) is defined by the ratio reactivity/**delayed neutron** fraction = 1; its submultiple is the *cent*.

**Doppler:** see **Doppler effect** and **Doppler coefficient**.

**Doppler coefficient:** a **reactivity coefficient** indicating, in terms of **pcm**/°C, the **Doppler effect** in a reactor.

**Doppler effect:** the fall in local **reactivity**, in a reactor, subsequent to a rise in **fuel** temperature. This instantaneous effect acts as a major safety factor. The **Doppler constant** is expressed in **pcm**.

**dose:** see **integral dose**.

**dosimetry:** the determination, by way of measurement or estimate, of **doses** of **ionizing** radiation absorbed, or liable to be absorbed, by a substance, or an individual.

**dpa:** the number of displacements **per atom**, induced in a material under **irradiation**. This unit indicates that, for *n* dpa, every atom in the material has undergone *n* displacements, on average, over the duration of irradiation.

**ductility:** the ability of a material to undergo plastic deformations while resisting propagation of the defects induced.

**effluents:** waste, in liquid or gaseous form.

**EFPD:** a unit of operating time, for a nuclear reactor, expressed in terms of "equivalent full-power days".

**EFR:** a European **sodium**-cooled fast reactor project, investigated in the 1980s and 1990s, standing as reference for this reactor line.

**electrolysis:** displacement of **ions**, under the influence of a difference in potential, towards **electrodes**, resulting in a deposit, or gaseous discharge at the electrodes of the oxidized or reduced species.

**electron:** a negatively-charged elementary particle. One of the constituents of the **atom**, orbiting around the **nucleus**.

**electronvolt (eV):** the energy gained by an **electron** accelerated by a potential of 1 volt: 1 **eV** = $1.6 \cdot 10^{-19}$ **joule**. The **megaelectronvolt** (1 **MeV** = $10^6$ eV) is used to express the energy released by nuclear reactions.

**element:** an **atom**, as defined by the number of its **protons** (**atomic number**). The term **light elements** (**hydrogen**, **helium**, lithium, beryllium, boron) refers to elements of atomic number lower than or equal to 5; while **heavy elements** cover the others, from carbon to **uranium**, as far as natural elements are concerned – though more specifically those elements of atomic number equal to or greater than 80 (all **actinides** and their daughter products being included in this group).

**enriched uranium (EU):** **uranium** in which content in **isotope** 235 has been increased from its low, natural level (0.72% by mass) to, for example, 3.5% for **fuel** intended for a pressurized-water reactor.

**enrichment:** a process whereby an **element** is made to reach an increased content with respect to one of its **isotopes**. In the case of **uranium**, this allows an increase in the concentration of isotope 235, relative to isotope 238, which is predominant in **natural uranium**.

**entropy:** a quantity, expressed in **joules** per **kelvin**, the variation of which is equal to the amount of heat supplied to a system by a reversible process, at a constant temperature, divided by that temperature. Entropy is a measure of the degree of disorder exhibited by a system.

**epithermal neutrons:** **neutrons** having an energy in the 10 **eV**–20 **keV** range (approximately), with a velocity higher than that of **thermal neutrons**.

**EPR (Evolutionary Power Reactor**, or **European Pressurized-Water Reactor):** a third-generation pressurized-water reactor (PWR) concept, developed by **Areva NP**, featuring improvements in terms of safety, **fuel** utilization, and operating economics.

**eutectic:** a mixture of two pure substances, melting and solidifying at constant temperature, and behaving as a pure substance, with respect to melting.

**fast neutrons:** **neutrons** released at the time of **fission**, traveling at very high velocity (20,000 km/s). They have an energy of around 2 **MeV**.

**feedback** (neutronic)**:** an effect of variations in certain reactor parameters (power, temperature, pressure, or void fraction) on **reactivity**. More particularly, a reaction tending to counterbalance the effect of a **neutronic** process.

**fertile:** term used to refer to a **nuclide** the **nucleus** of which may be transformed, directly or indirectly, into a **fissile** nucleus, through **neutron capture**. Also used to refer to a material consisting of fertile **atoms**.

**fertile blanket:** **fertile** material, positioned at the core periphery, in a **fission** reactor (in particular in a fast reactor, i.e. using **fast neutrons**), for the purposes of transforming it into **fissile material**.

**% FIMA (fission per initial metal atom):** a unit of **burnup** for nuclear **fuels**, corresponding to the number of **fissions** per initial heavy metal atom, expressed in terms of the proportion of fissions occurring in a population of atoms. The correspondence with **specific burnup** (MW · d/$t_M$) stands at 1% FIMA ≅ 9,600 MW · d/$t_M$.

**fissile:** term used to refer to a **nuclide**, or material, the **nuclei** of which are liable to undergo **fission** through **neutron** absorption (it is not the "fissile" nucleus that undergoes fission, rather it is the compound nucleus formed subsequent to a neutron **capture**).

**fission:** the splitting of a **heavy nucleus** into two fragments, with concomitant emission of **neutrons**, radiation, and a considerable release of heat.

**fission products:** **nuclides** yielded either directly, by nuclear **fission**, or indirectly by the **decay** of fission fragments. These may be gaseous (**fission gases**), or solid (volatile or otherwise).

**fission rate:** **fission burnup**, or **burnup fraction** (at %).

**fluence:** a unit of **dose**, used to quantify the **irradiation** of materials. The number of incoming particles (namely **neutrons**) per unit surface, over the duration of irradiation.

**formulary (neutronic):** a tool for the computation of physical quantities of interest, comprising nuclear data *libraries*, **software** programs, and validated, qualified computation procedures.

**fossil:** a term used to refer to a **hydrocarbon** fuel, such as coal, petroleum or natural gas, originating in deposits formed by the accumulation, and transformation of organic matter. Also used to refer to the forms of energy yielded by such fuels.

**fuel (nuclear):** a **fissile** material, enabling, through use of an appropriate geometry, a **chain reaction** to be sustained inside the core of a reactor; **fuel element**: the smallest core component; **spent fuel**: fuel which, being unable to further sustain the nuclear reaction, is discharged from the reactor.

**fuel cell:** an electrochemical device (**electrodes**, separated by an **electrolyte**), supplied with **hydrogen**, and oxygen, generating electricity through the direct conversion of the fuel's chemical energy, while also yielding water.

**fusion:** an energy production process involving the fusion of **light element nuclei** (**hydrogen isotopes**). **D–T fusion** involves **deuterium**, and **tritium**.

**gamma:** see **radioactivity**.

**gamma radiation:** highly penetrating, if poorly **ionizing**, electromagnetic radiation, emitted in the form of **photons** in the **decay** of **radioactive elements**.

**gamma spectrometry:** the measurement of **gamma radiation** energies, for the purposes of analyzing a mixture of **radioactive** substances.

**grains:** the elementary *crystallites*, making up a metal.

**graphite:** one of the three forms of carbon exhibiting a **crystal** structure, made up of **graphene** sheets, in which every **atom** is bound to three of its neighbors.

**greenhouse gas (GHG):** a gas the presence of which in the atmosphere tends to augment the natural greenhouse effect. The main such gases are **carbon dioxide** ($CO_2$), water vapor, methane, and chlorofluorocarbons.

**H+ proton:** a **hydrogen atom**, which has been stripped of its **electron**. It is not normally to be found in a free state, however it may share electrons with **ions**, or **molecules**.

**half-life (radioactive):** the time required for one half of the **radioactive atoms** initially present to disappear from natural causes, through **radioactive decay**.

**heat conductivity:** see **thermal conductivity**.

**heavy ions:** positively-charged **atom nuclei**, with a mass higher than that of the **helium** 4 nucleus (**alpha** particle).

**helium:** the lightest chemical **element** (He), after **hydrogen**. Its **nucleus** comprises two **protons**, and two **neutrons** for **helium 4**. The nucleus of the most common **isotope** (**helium 3**) features just one neutron.

**hexagonal tube:** a structure used in particular for **fuel-pin assemblies** in fast reactors, allowing each assembly to be set apart as a quasi independent **thermalhydraulic** circuit.

**homogeneous (mode, pathway)/heterogeneous (mode, pathway):** the manner in which the **radionuclides** due to undergo **transmutation** are loaded into a reactor, i.e. blended into **fuel**, or concentrated inside targets.

**hot (laboratory):** a laboratory featuring shielded **cells**, allowing the processing, by means of remote handling, of **high-activity** materials, placed in an enclosure ensuring confinement of the materials, and operator protection.

**hot isostatic pressing:** a process involving simultaneously bringing to bear, on a material, high pressures ($10^8$–$1.5 \cdot 10^8$ **Pa**) and high temperatures (around 1,000 °C), by way of a neutral gas.

**hot leg:** in a gas-cooled reactor, the piping connecting the core and the energy conversion system, channeling high-temperature gas.

**hybrid (system):** see **ADS**.

**hydrocarbons: molecules** consisting solely of carbon, and **hydrogen**, forming in particular the constituents of petroleum, and natural gas.

**hydrogen:** a chemical **element** (H), having three **isotopes**, one of which is an **atom** simply comprising one **proton**, and one **electron**; the other isotopes are **deuterium**, and **tritium**.

**hydrometallurgical** (path)**:** in **spent fuel reprocessing**, the path involving its dissolution in an acid medium, and use of liquid–liquid extraction processes.

**incineration (of radioactive waste):** a term used, improperly, to refer to the **transmutation**, inside a nuclear reactor, of **actinides**, particularly **minor actinides**, through **fission**, and **neutron capture**.

**infrared (IR) radiation:** a segment of the electromagnetic spectrum covering radiation of wavelengths ranging from 760–780 **nm** to 1 mm.

**integral dose** (or **dose**)**:** a term used to estimate, in a material, the integral **neutron flux** (i.e. neutron **fluence**) over its **irradiation** time. This is expressed in $n/m^2$.

**intermediate heat exchanger (IHX):** the heat exchanger inserted between the primary (**helium**) circuit, and the secondary circuit (using e.g. nitrogen), in a gas-cooled reactor.

**inventory (radionuclide):** the amount of **fission products** and **actinides** contained in an irradiated **fuel**, as a rule expressed in **becquerels** per gram, or tonne initial heavy metal (Bq/giHM, or Bq/tiHM).

**ion:** an **atom**, or **molecule** that has lost, or gained, one or more **electrons**, and is thus electrically charged, positively (**cation**), or negatively (**anion**).

**irradiation:** the exposure to a form of radiation, and, more broadly, the outcome of such exposure.

**isotopes:** forms of one and the same chemical **element**, for which the **nuclei** have the same number of **protons** (and hence of surrounding **electrons**), but different numbers of **neutrons**.

**isotopic vector:** a description, in terms of percentages, of the various respective fractions of each **isotope** found in a chemical **element** (e.g.: the **plutonium** vector).

**joule:** unit (**J**) of work, defined as the work done by a force of 1 newton, when its point of application is displaced 1 m in the direction of the force: 1 J = 2.778 · 10– $^{7}$ **kilowatt–hour**.

**kelvin (K):** unit of temperature. The Kelvin scale uses as its fixed point the thermodynamic temperature of the triple point of water (i.e. the point at which the three phases, solid, liquid, and vapor, coexist), at 273.16 K, i.e. 0.01 °C. "Absolute zero" corresponds to zero molecular agitation.

**kilowatt–hour (kWh):** the main multiple of the **watt–hour** (**Wh**), a unit of work and energy, the product of power multiplied by time (1 kWh = 3.6 million **joules**). Other multiples: the **megawatt–hour** (**MWh**), and the **gigawatt–hour** (**GWh**).

**lanthanides:** the family of elements (making up, together with yttrium and scandium, the group of **rare earths**) of **atomic number** (i.e. the number of **protons** in the **nucleus**) ranging from 57 (lanthanum) to 71 (lutetium). Lanthanides (**Ln**) exhibit chemical properties that are very close to those of **actinides**.

**light nuclei, heavy nuclei:** see **element**.

**light water:** ordinary water ($H_2O$), as opposed to **heavy water** (**deuterium** monoxide [$D_2O$]), in which deuterium is substituted for the "light" **isotope** of **hydrogen**.

**linear power:** the power released per unit length of **fuel pin**. Temperature is proportional to linear power, expressed in **W**/m.

**liquid metals:** as used as coolants in nuclear reactors, these chiefly include **sodium**, and lead and lead **alloys** (e.g. alloyed with bismuth).

**long-lived:** a term used to refer to **radionuclides** having a half-life longer than 30 years (other radionuclides being termed **short-lived**), contained, in particular, in long-lived waste, whether of intermediate activity ("intermediate-level" waste : LL–ILW), or **high activity** ("high-level" waste: **LL–HLW**).

**loop:** a setup serving to circulate a fluid along a closed circuit. More broadly, a device dedicated to the investigation of a given process. In a reactor, the ensemble of components serving to circulate the coolant. **Loop reactor**: a configuration whereby the main components (vessel, heat exchangers) are connected by means of ducts forming loops, within which pumps, or compressors ensure forced circulation of the coolant. In designs featuring an **integral** primary circuit, these components are brought together, inside a vessel.

**major actinides: uranium** and **plutonium nuclei**, present in, or generated within nuclear **fuel**.

**matrix:** the coating material, in a **composite**, particularly for the **fissile** materials in a nuclear **fuel**.

**micrometer (or micron):** 1 **µm** = $10^{-6}$ **meter**.

**minor actinides (MAs): heavy nuclei**, generated in relatively small amounts in reactors, through successive **neutron captures** by **fuel nuclei**. The main such **elements** are **neptunium**, **americium**, and **curium**.

**modeling:** the working out of a simplified representation (a **model**) for a system, or process, for the purposes of simulating it, which is then drawn up in a **computation software**.

**moderation ratio:** in a reactor, the ratio of the quantity of moderator material, over the quantity of **fuel**.

**molecule:** a group of **atoms**, held together by chemical bonds.

**molten salts:** liquid media, comprising at least one type of **anion**, and one type of **cation**, and involving no **molecular solvent**. In a nuclear system, they may act both as **fuel** and **coolant**, or even as **spallation** target, in the form of **halides**, forming a chemically highly stable **ionic** medium. *Fluorides*, and *chlorides* prove suitable, respectively, for **thermal-neutron**, and **fast-neutron** reactors (fast reactors).

**Monte-Carlo method, or computation:** a statistical method, used to solve complex computations, or computation tasks not amenable to a deterministic method (whether analytical, or numerical), which are then solved through the random exploration, over a large number of instances, of the domain across which the problem variables vary.

**MOX (mixed oxides):** a mixture of (**natural**, or **depleted**) **uranium** oxide, and **plutonium** oxide.

**MSWU:** see **SWU**.

**multiplication factor *k*:** the ratio, over a given time interval, of the number of **neutrons** yielded by **fission**, over the number of neutrons disappearing. In an infinite medium, involving no **neutron leakage**, this is noted $k_\infty$; in a finite medium, this is termed the **effective multiplication factor** (noted $k_{eff}$).

**multirecycling:** see **recycling**.

**nano-:** a prefix (symbol **n**) indicating one billionth ($10^{-9}$); 1 **nanometer** (**nm**) = $10^{-9}$ meter.

**natural uranium (NU):** a natural **radioactive element**, present in a number of ores, pitchblende in particular. It occurs in the form of a mixture of **isotopes**, comprising: **fertile** $^{238}U$, to a proportion of 99.27%, **fissile** $^{235}U$ (0.72%), and $^{234}U$ in the form of traces, to less than 0.01%.

**neutron:** an electrically neutral fundamental particle, having a mass of $1.675 \cdot 10^{-27}$ kg. Neutrons are the constituents, together with **protons**, of **atomic nuclei** (**nucleons**). They can cause the **fission** of **fissile** nuclei, in nuclear reactors (see also: **delayed neutrons**, **epithermal neutrons**, **fast neutrons**, **prompt neutrons**, **thermal neutrons**).

**neutron absorber:** a material, bearing **neutron**-absorbent **nuclides**, used to control **reactivity** in reactors.

**neutron capture: absorption** of a free **neutron** by a **nucleus**, not resulting in **fission**.

**neutron flux:** the number of **neutrons** passing across the unit surface, per unit time.

**neutron leakage:** the fraction of **neutrons** that escape from a multiplying medium, thus taking no part (or no further part) in the **chain reaction**.

**neutron spectrum:** the energy distribution of the **neutron** population present in a reactor core.

**neutronics:** the study of the paths followed by **neutrons** in **fissile**, or nonfissile media, and of the reactions they induce in matter, in particular inside a nuclear reactor, with regard to their multiplication, and the initiation, and control of the **chain reaction**.

**nitride** (actinide)**:** a chemical form used for **fuel**, in which the **fissile element** (**uranium, plutonium**) is combined with nitrogen, rather than oxygen as in **oxide** fuels.

**nucleus** (**atomic**)**:** the central constituent in an **atom**, bearing a positive charge and comprising **protons** and **neutrons** (except in the case of the light **isotope** of **hydrogen**), around which **electrons** orbit.

**nuclide:** a nuclear species, characterized by its number of **protons** *Z* (i.e. its **atomic number**), number of **neutrons** *N*, and mass number *A*, this being equal to the sum of the number of protons and number of neutrons ($A = Z + N$).

**numerical simulation:** the mimicking, by way of computation, of the functioning of a system, subsequent to its prior description through a **model**, or an ensemble of models.

**oxide** (**fuel**)**:** a **fuel** in which the **actinides** are in oxide form.

**partitioning:** a chemical process, forming part of the **reprocessing** operations, whereby the various constituent **elements** of **spent fuel** are separated.

**pascal:** the legal unit of pressure (**Pa**). Its multiples include the megapascal (**MPa**).

**passivity:** a term used to describe systems based on natural actions and forces, such as **convection** and gravity, making the safety of an installation less dependent, in theory, on active systems (pumps, motors, etc.).

**pcm:** a unit of **reactivity** (abbreviation of "percent millirho").

**pellet:** a cylindrical **fuel element**, made from **ceramic**, a stack of which, inside the cladding tube, forms the **fissile** column (in a **rod**, or **pin**), in a reactor. Pellets are obtained, for most current reactors, through compaction of **uranium** oxide (**UOX**) powder, or mixed uranium and **plutonium** oxide (**MOX**) powder.

**photon:** the quantum of energy of an electromagnetic radiation. An elementary particle, having zero mass and no electric charge, associated to such radiation.

**pin:** a form of **fuel element**, akin to the **rod** used in PWRs, more specifically used in fast reactors.

**plasma:** a state of matter in which matter is brought to a temperature such that most, or all of its **atoms** are **ionized**.

**plenum:** a distribution (or admission) chamber (or receiver), filled with a fluid. By analogy, a "**sodium plenum**", positioned above the core of a reactor, is a volume of sodium, located inside the axial reflector, featuring very little by way of solid materials, which, when voided at a time of hypothetical coolant boiling, allows an enhancement of the **leakage** component in the **void** effect, thus bringing down void **reactivity**. The term also refers to the space provided inside a **fuel element**, to receive **fission gases**.

**plutonium:** chemical **element** (Pu) of **atomic number** 94, having **isotopes** ranging from $^{232}Pu$ to $^{247}Pu$. Five of these isotopes are important, in industrial terms, from $^{238}Pu$ to $^{242}Pu$, especially $^{239}Pu$ (which is **fissile**), generated inside reactor cores from uranium 238, through **neutron capture**. The unevenly-numbered isotopes are fissile, Pu consequently being a recoverable nuclear material, for value-added purposes, e.g. for use in the form of **MOX**.

**point defect:** a defect occurring at one point in a **crystal** lattice, owing either to a missing atom (**vacancy**), or to a supernumerary atom, located between normal atom positions (**interstitial**), or yet to an extraneous atom, substituted for one of the atoms in the lattice. **Irradiation defect**: a point defect due to **irradiation**.

**poison** (**neutron**)**:** an **element** exhibiting a high neutron **capture capability**, used to counteract, at least in part, excess **reactivity** in **fissile** media. Some **burnable** poisons vanish gradually.

**poisoning** (fuel)**:** a **neutron capture** process, due to certain **fission products** building up in the course of **irradiation**.

**pool-type reactor:** a type of nuclear reactor in which the core is positioned in a pool of water, the water serving as coolant, moderator, and biological protection shield.

**positive breeding gain:** a condition allowing, in a nuclear reactor (**breeder** reactor), more **fissile** material to be generated than is consumed by the reactor, new fissile **nuclei** being generated through the **capture** of **fission neutrons** by **fertile** nuclei, subsequent to a number of **radioactive decays**.

**potential radiotoxicity** or **radiotoxic inventory:** the product of the **activity** of a certain quantity of **radionuclides**, multiplied by *ingestion dose factors*: this is the **dose** that would be received by a group of individuals taking in that amount of material.

**power density** (**core**)**:** a quantity (expressed in **kW** $\cdot L^{-1}$, or **MW** $\cdot m^{-3}$) which, when multiplied by the volume of **fuel** in a nuclear reactor, gives the amount of heat released by the **fission** process.

**precipitation:** the formation of a solid phase, from constituents in dissolved form.

**pressure drop:** in a device channeling a fluid (e.g. a heat exchanger), the effect due to friction, altering pressure, which ceases to remain constant. This is expressed in **MPa**, or **bars**.

**proliferation:** the uncontrolled dissemination of nuclear technologies, or nuclear materials, for military uses.

**prompt neutrons: neutrons** released directly at the time of **fission**.

**protons:** fundamental particles bearing a positive electric charge, the constituents, together with **neutrons**, of **atomic nuclei**.

**Purex** (Plutonium Uranium Refining by EXtraction)**:** a **hydrometallurgical** process for the separation of **uranium** and **plutonium** from **spent fuel**.

**pyrocarbon**, or **pyrolytic carbon: amorphous** carbon, yielded by the high-temperature decomposition of a gaseous **hydrocarbon**, used as a coating layer in the makeup of **fuel** particles.

**pyrochemistry, pyrochemical path:** the use of temperatures of several hundred °C, to carry out chemical operations, in particular the partitioning of **long-lived radionuclides**, in nonaqueous media, not involving organic **molecules**, but liquid metals, and **molten salts**.

**pyrolytic carbon:** see **pyrocarbon**.

**radioactive daughter nuclide:** a **radionuclide** yielded by the spontaneous **decay** of another nuclide.

**radioactive decay:** the falloff, over time, of the **activity** exhibited by a **radioactive** source, owing to the random occurrence of **decays** in a population of **atomic nuclei**, which are unstable by definition.

**radioactivity:** the property, exhibited by certain natural or artificial **elements**, of spontaneously emitting, as they **decay**, **alpha** particles (**helium** nuclei), **beta** particles (positrons [beta+ emission] or **electrons** [beta– emission]), and/or **gamma** radiation (high-energy **photons**). More broadly, this term is used to refer to the emission of radiation concomitant with the decay of an unstable element, or **fission**.

**radioelement:** an **element** all **isotopes** of which are **radioactive**.

**radiolysis:** the chemical decomposition of matter (organic matter in particular) by **ionizing** radiation.

**radionuclide:** a **radioactive isotope**, also known sometimes as a **radioisotope**, of an **element** (see **nuclide**).

**rare earths:** see **lanthanides**.

**reaction rate:** the number of reactions intervening between **neutrons** and matter, per unit volume, per unit time.

**reactivity:** a dimensionless quantity, used to evaluate small variations in the **multiplication factor *k*** around the critical value, and defined by the formula: $\rho = (k - 1)/k$. Its value being very small, it is as a rule expressed in percent millirho (**pcm** unit): this refers to **absolute reactivity**. In a reactor, there is zero reactivity when the reactor is **critical**; reactivity is positive when it is **supercritical**, and negative when it is **subcritical**. **Delayed neutrons** playing a major role in reactor control, reactivity may be expressed as a function of the effective delayed neutron fraction (**effective β**, or $\beta_{eff}$). This then refers to **relative reactivity**, expressed in **dollars**, which takes into account the variation in reactivity. A reactor will not be *prompt critical* so long as it exhibits reactivity lower than 1 dollar.

**reactivity coefficient:** a variation in the **multiplication factor**, due to reactor operation, i.e. resulting from changes in temperature, and composition, due to the release of energy, and **neutron irradiation** (see also: **Doppler coefficient**, **temperature coefficient**, **void coefficient**).

**recoil nucleus:** a **nucleus** to which, subsequent to a nuclear reaction, or a **radioactive** emission, kinetic energy is imparted. In an **elastic interaction**, the incident particle rebounds off the target particle with a kinetic energy lower than its initial energy. The transferred momentum imparted to the target causes it to recoil.

**recycling:** the recovery of reusable materials, after a production process. In a nuclear reactor, the reuse of **fissile** materials (generated **plutonium**, residual **uranium** 235…) yielded by a previous cycle, after **reprocessing** of the **spent fuel**: **monorecycling**, in the single-**irradiation** case; **multirecycling** when several successive passes are involved. Recycling may be **homogeneous** (the materials being blended into all of the fuel), or **heterogeneous** (the materials are held in target assemblies).

**reflector:** a massive metallic structure positioned at the periphery of a reactor vessel, to reflect those **neutrons** yielded by nuclear reactions that have not been absorbed as they travel through the core. This allows such neutrons to be recovered, while avoiding their causing accelerated **irradiation** aging of the vessel.

**reprocessing** (or **treatment**) (spent fuel)**:** the selective sorting of substances contained in **spent fuel**, in order to extract those that are recoverable, and **recyclable** (**uranium**, and **plutonium**), or possibly amenable to **transmutation**, while conditioning the ultimate waste.

**residual power:** see **decay heat**.

**resolution**: the resolving power, i.e. the ability to discriminate, of an observation or detection device.

**rod:** a tubular **fuel element**, of small diameter, closed at both ends, used as a component of a nuclear reactor core, holding **fissile**, **fertile**, or neutron-absorbent **material**.

**sintering:** a treatment involving the welding together of **grains** of precursor powders (metal, or **ceramic**), by compacting them at a temperature lower than the melting point for the main constituent, in order to form them into a continuous solid, or a new ceramic.

**sodium:** an alkali metal, used in the liquid state as a coolant for **fast-neutron** reactors (i.e. fast reactors), owing to its "transparency" to **neutrons**.

**sol–gel** (path)**:** a chemical synthesis process, using a solution holding reactive precursors, such as alkoxides or metal salts, involving two steps: **hydrolysis**, and condensation (formulation of a covalent network). The **colloid** suspension (*sol*) consists of a solid phase, **dispersed** in a liquid. After condensation, the solution evolves to form a system imprisoning the **solvent**: the *gel*.

**spallation:** a nuclear reaction involving a target **heavy nucleus** and a particle (most commonly a **proton**), accelerated to an energy ranging from a few hundred **MeV** to several **GeV**. By way of successive reactions, a beam of such particles allows a large number of **neutrons** to be generated.

**specific burnup** (see also **burnup**): the total amount of energy released per unit mass, in a nuclear **fuel**. This is expressed by operators in terms of megawatts–day per tonne (MW · d/t).

**specific power** (**fuel**)**:** power, referred to the volume of the smallest **fuel element** (expressed in **kW**/cm$^3$).

**spectrum hardness** (**neutron**)**:** this refers to the average **neutron** energy level. A "hard spectrum" involves high-energy neutrons, while its "softening" involves a reduction in their energy.

**stoichiometry:** the study of the proportions according to which, in a chemical reaction, reactants combine and products are formed. A reaction is said to be **stoichiometric** when reactant quantities stand in molar proportions identical to those appearing in the chemical equation.

**stress:** the force acting on a structure, whether constantly, or in transient fashion. This is expressed per unit surface.

**subcritical:** a term used to refer to a system (a reactor core, in particular) where the number of **neutrons** released by **fission** is lower than the number of neutrons disappearing through absorption, and **leakage**.

**supercritical** (**fluid**)**:** a fluid which, brought to temperature and pressure conditions higher than those prevailing at its *critical point*, exhibits a viscosity close to that of the gas, density close to that of the liquid, and high diffusivity. Its solvent power varies with pressure and temperature conditions. The most commonly used are **carbon dioxide** (**$CO_2$**), owing to its low critical temperature (31 °C), and water ($H_2O$).

**swelling:** a deformation, due to **irradiation**, caused by the nucleation, and growth of cavities, formed by the accumulation of **vacancies**, along with the **precipitation** of **helium** into bubbles.

**SWU:** *separative work unit*, used to evaluate the production capacity of an **enrichment** plant. It is proportional to the amount of **uranium** processed, and provides a measure of the work required to separate the **fissile isotope** (multiple: 1 **MSWU** = 106 SWU).

**temperature coefficient:** the ratio, in a nuclear reactor, or any other multiplying medium, of the variation in **reactivity** (**multiplication factor**), over the variation in average temperature causing this variation. It may be positive or negative, and is expressed in **pcm**/°C.

**thermal conductibility:** the property, exhibited by a substance, of conducting heat, **heat conduction** being the process whereby, in a medium, heat flows from a high-temperature region to another, lower-temperature region, or from one medium to another coming into contact with it.

**thermal conductivity:** characterizes the resistance to the flow of heat through a homogeneous material; this expresses, in terms of **W** · $m^{-1}$ · **K**$^{-1}$, the rate at which heat flows across a surface, per unit temperature variation along a direction perpendicular to that surface.

**thermal cycling:** the alternation of heating and cooling stages.

**thermal diffusivity:** the penetration velocity of a thermal wave inside a medium; the ratio (expressed in $m^2/s$) of **conductivity**, over the product of density by specific heat.

**thermal neutrons:** also known as slow (or **thermalized**) **neutrons**, these are neutrons in thermal equilibrium with the material within which they travel, at a velocity of some 2–3 km/s. Their energy stands at less than 1 **eV**. They are known as "highly thermal" neutrons, when they have been particularly slowed down.

**thermalhydraulics:** the part of physics concerned with heat transfers and fluid mechanics.

**thermalization:** the slowing down of (**fast**) **neutrons**, in order to bring them gradually into thermal equilibrium with the reactor material in which they scatter.

**thermochemistry:** the use of heat (supplied, in this case, by a nuclear reactor) to enable chemical reactions, resulting e.g. in **hydrogen** production through the splitting of water **molecules**.

**thorium:** a heavy chemical **element** (atomic number 90), of symbol Th, fairly abundant in nature, having **isotopes** ranging from $^{223}$Th to $^{235}$Th. Isotopes $^{227}$Th, $^{229}$Th and $^{233}$Th are **fissile** by means of **thermal neutrons**. Natural isotope $^{232}$Th may be used as **fuel**, by way of a cycle analogous to that of **uranium** 238, in fast reactors (**using fast neutrons**), and as **fertile** material (yielding $^{233}$U as primary fuel).

**toe:** a unit of energy, corresponding to one tonne oil equivalent, i.e. 1 toe = 42 billion **joules** or 11,630 **kWh**. Multiples: the **Mtoe** ($10^6$ toe), and **Gtoe** ($10^9$ toe).

**toughness:** a characteristic quantity for a material, expressed in **MPa** · $m^{1/2}$, a measure of its resistance to crack propagation.

**transient:** a time interval during which a system is not in a state of equilibrium. A slow, or rapid evolution, whether scheduled or unexpected, in the operating state of an installation.

**transmission electron microscopy (TEM):** a microscopy technique based on the principle of **electron** diffraction, allowing a **resolution** of around 0.1 nm to be achieved.

**transmutation:** the transformation, by means of a **neutron**-induced nuclear reaction (**capture**, **fission**), of one **isotope** into another, and, more particularly, the transformation of a **long-lived radioactive** isotope into a short-lived , or stable isotope.

**transuranic elements** (**TRU**)**:** all **elements** having a number of **protons** in their **nucleus** greater than that of **uranium**. In a reactor, this refers to the **heavy nuclei** yielded by uranium through **neutron capture**, or forms of **radioactive decay** other than **fission**. These fall into six families of **isotopes**, aside from uranium: **neptunium**, **plutonium**, **americium**, **curium**, and, beyond, berkelium, californium...

**treatment:** see **reprocessing**.

**TRISO:** a type of **fuel** in particle form, used for high-temperature reactors, comprising a kernel of **fissile** or **fertile** material, coated with four succeeding layers: porous pyrocarbon, dense **pyrocarbon**, silicon carbide (SiC), and dense pyrocarbon.

**tritium:** the heaviest **isotope** of **hydrogen**, and the only **radioactive** one. Its **nucleus** comprises one **proton**, and two **neutrons**.

**turbine engine:** a heat engine, for which the motive component is a turbine, generating torque by means of the expansion of gases passing through it. Primary energy may be provided by burning an air–kerosene mixture (aviation reactors and compressors), or an air–natural gas mixture (electric power plants). The turbine drives a compressor, which strongly compresses the air, prior to its admission into the combustion chamber.

**turbulence:** a flow mode in fluids, for which, onto the mean motion, a random agitation motion is superimposed.

**ultrasounds:** acoustic waves of a frequency higher than 20 kHz, inaudible to the human ear.

**$UO_2$: uranium** dioxide, the standard form of uranium **fuel** for **light-water** reactors.

**UOX:** the standard form of **light-water** reactor **fuel**, consisting of **uranium** 235-**enriched uranium** oxide.

**uranium:** a chemical **element** (U) of **atomic number** 92, having three natural **isotopes**: $^{234}$U, $^{235}$U ("**U5**", the sole **fissile** isotope), and $^{238}$U (see also: **depleted uranium**, **enriched uranium**, **natural uranium**).

**vitrification:** an operation consisting in solidifying, after mixing at high temperature with a mineral glass paste (nuclear **glass**), concentrated solutions of **fission products** and **transuranic elements**, extracted through **reprocessing** of **spent fuel**.

**void:** see **void effect**.

**void coefficient:** a coefficient expressing the variation in the **multiplication factor** of a reactor, when the coolant exhibits greater void formation (e.g. bubbles, in water) than normal (surplus void content). If this coefficient is positive, a surplus (of steam, in this case) will result in increased **reactivity**, and power. If it is negative, that surplus will tend to bring the reactor to a halt. The void coefficient is expressed using the **dollar** or **pcm** as units.

**void effect:** the effect on **reactivity**, in a nuclear reactor, expressed in **dollars**, due to a surplus void content forming in the moderator, or the coolant. When the latter is **sodium**, this is known as the **sodium void effect**.

**volumetric power:** the power of the core of a nuclear reactor, referred to its volume; this is expressed in **W**/$m^3$.

**watt:** a unit of power (**W**), corresponding to production (or consumption) of one **joule** per second. Main multiples: the kilowatt (1 **kW** = $10^3$ watts), the megawatt (1 **MW** = $10^6$ watts), the gigawatt (1 **GW** = $10^9$ watts), and the terawatt (1 **TW** = $10^{12}$ watts). Thermic power is expressed in **Wth**, **MWth**, or **GWth**; electric power in **We**, **MWe**, **GWe**, or even **TWe** (for a fleet of power plants).

**Young's modulus** (or **longitudinal modulus of elasticity**)**:** for an "elastic" material, subjected to traction or compression **stresses**, the ratio, determined lengthwise, of the variation in stress, over the variation in strain (deformation). Derived as it is from Hooke's law (strain is proportional to stress), this is expressed in terms of pressure, as a rule measured in **MPa**.

**zero breeding gain:** refers to a process whereby as much **fissile fuel** is generated as is consumed.