GLOSSARY OF NUCLEAR TERMS

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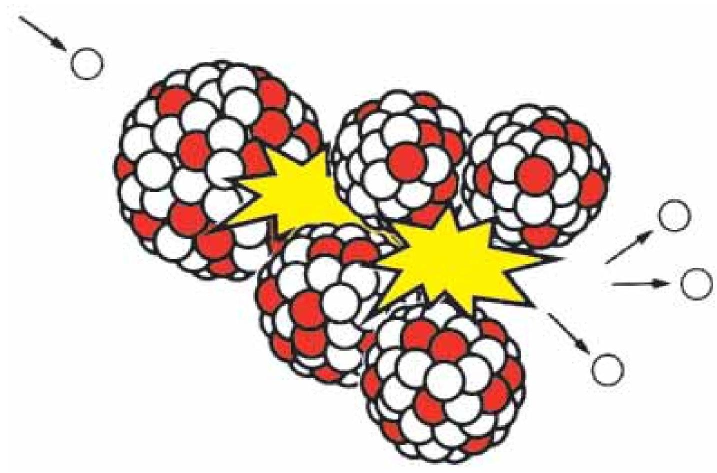

Edition February 2013

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Postfach 3640
76021 Karlsruhe
Germany

ISBN German print version 2001: 3-923704-32-1

Translation by Informationskreis KernEnergie, Berlin

Version February 2013

This version includes all updates and additions made since the last printing conducted in 2001.
The layout of this version has not been optimized.

Pictures:
Argonne National Lab., Argonne
Aulis-Verlag Deubner & Co. KG, Köln
Informationskreis Kernenergie, Berlin
Karlsruher Institut für Technologie, Karlsruhe

A

Absorbed dose

The absorbed dose *D* is the quotient of the average energy transferred to the matter in a volume element by ionizing radiation and the mass of the matter in this volume element:

$$D = \frac{d\bar{\varepsilon}}{dm}.$$

The unit of the absorbed dose is joule divided by kilogram ($J \cdot kg^{-1}$) and its special unit name is gray (Gy). The former unit name was rad (symbol: rd or rad).1 Gy = 100 rd; 1 rd = 1/100 Gy.

Absorbed dose rate

Quotient of absorbed dose per unit of time. Unit: Gy/h.

Absorber

Any material "stopping" ionizing radiation. Alpha radiation can already be totally absorbed by a sheet of paper; beta radiation is absorbed by a few centimetres of plastic material or 1 cm of aluminium. Materials with a high →atomic number and high density are used for gamma radiation absorbers (lead, steel and concrete, partially with special additions). Neutron absorbers such as boron, hafnium and cadmium are used in control rods for reactors.

Absorber rod

→control rod

Accelerator

Device to accelerate electrically charged particles to high energies. Accelerators include e.g.: →betatron, →linear accelerator, →synchrotron, →synchro-cyclotron, →Van de Graaff generator and →cyclotron.

Accident

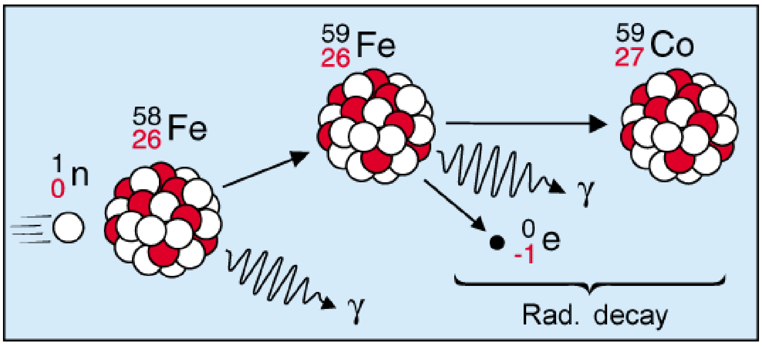
Sequence of events which may result in an effective dose of more than 50 millisievert for at least one person.

Accounting

Most important method of →nuclear material control in a nuclear facility. Its goal is the quantitative determination of the nuclear material to detect inventory deficiencies (unauthorised diversions). The accounting relates to a defined, limited, walled-in space the contents of which results from the difference of all continuously measured nuclear material additions and withdrawals. At the end of the accounting period the plant inventory is determined by an independent direct measurement. →MUF

Activation

Process to make a material radioactive by bombardment with neutrons, protons or other particles.



Activation of iron

Activation analysis

Procedure for the quantitative and qualitative determination of chemical elements in a sample to be analysed. The sample becomes radioactive through bombardment with neutrons or charged particles. The resulting radioactive atoms of the sample emit characteristic rays by which the type of atoms can be identified and the quantity measured. The activation analysis is frequently more sensitive than a chemical analysis and is used increasingly in research, industry, archaeology and criminology.

Activation cross section

Measure of the probability of the occurrence of a reaction. The cross section is the apparent surface which a target nucleus exposes to an arriving particle. The cross section is indicated in surface units. Neutron cross sections are frequently measured in the unit of barn, symbol: b. 1 barn is equal to 10^{-28} m^2.

Active beam

The bundle of rays emitted by a radiation source, e.g. an x-ray tube. Normally, it is limited to the required size by a diaphragm arrangement.

Activity

Activity is the term used to characterise the number of nuclei which disintegrate in a radioactive substance per unit time usually measured in Becquerel (Bq); a Bq is 1 disintegration per second. Replaces the former unit →curie, symbol: Ci. 1 Ci is equal to 37 000 000 000 Bq. Note: "Activity" is a quantitative term whereas 'radioactivity' is a qualitative term used to describe atoms that decay.

Activity concentration

Quotient of the activity 'A' of a material and the volume 'V' of this material, $A_{conc} = A / V$. Unit: Bq/m^3.

Activity intake

The quantity of radioactive substances inhaled or ingested through mouth or nose or which penetrates the intact or injured skin.

Activity, specific

Quotient of the activity 'A' of a material and the mass 'm' of this material, $A_{sp} = A / m$. Unit: Bq/kg.

After-heat

Thermal power of a reactor resulting from the →residual heat in the shut-down reactor.

AGR

Advanced Gas-Cooled Reactor. A total of 15 reactor units of this type are in operation in England and Scotland. AGR reactors use enriched uranium as fuel, graphite as moderator and CO_2 as cooling gas.

Air lift

Process-based transport and dosing equipment where air is used as a carrier for liquids, e.g. to transport highly active liquids. An air lift has no moving parts and requires twice to five times as much carrier air volume as the transported liquid volume.

ALARA

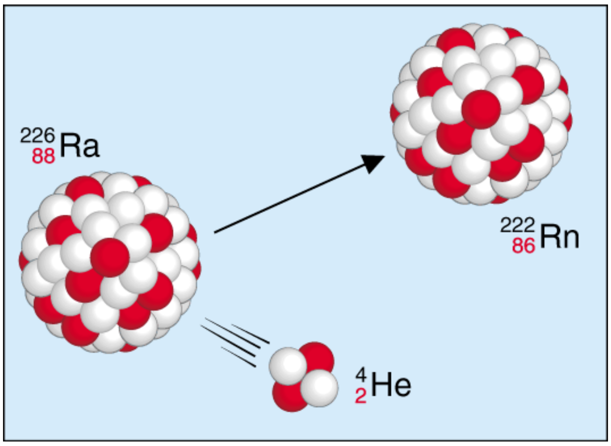
Acronym for **A**s **L**ow **A**s **R**easonably **A**chievable. Concept of the International Commission on Radiological Protection for dose limitation, described in detail and substantiated in the recommendation of the International Commission on Radiological Protection of 1990, published in 1991 as →ICRP Publication 60.

ALI

Annual **L**imit on **I**ntake →annual limit on intake

Alpha decay

Radioactive conversion emitting an alpha particle. During alpha decay the →atomic number is reduced by two units and the →mass number by four units. For example, alpha decay generates Rn-222 with the atomic number 86 and the mass number 222 from Ra-226 with the atomic number 88 and the mass number 226.



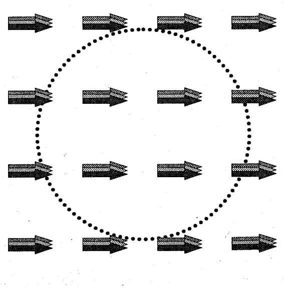
Alpha decay; the figure shows the decay of radium-226 into radon-222 emitting helium with 4 nucleons (2 protons and 2 neutrons = 1 alpha particle, α-particle)

Alpha particle

Positively charged particle emitted by various radioactive materials during decay. It consists of two neutrons and two protons, and is thus identical to the nucleus of a helium atom. The rest mass of the alpha particle amounts to $6.64424 \cdot 10^{-27}$ kg, or $3.7273 \cdot 10^{9}$ eV. Alpha radiation is the radiation with the lowest penetration potential of the three radiation types (alpha, →beta, →gamma radiation). Alpha radiation can already be stopped by a sheet of paper and is only dangerous for living creatures if the substance emitting alpha rays is inhaled or ingested with food or enters wounds.

Ambient dose equivalent

The ambient dose equivalent H*(10) at the point of interest in the actual radiation field is the dose equivalent which would be generated in the associated oriented and expanded radiation field at a depth of 10 mm on the radius of the ICRU sphere which is oriented opposite to the direction of incident radiation. An oriented and expanded radiation field is an idealized radiation field which is expanded and in which the radiation is additionally oriented in one direction.



Schematic representation of an oriented and expanded radiation field

Amplitude analysis

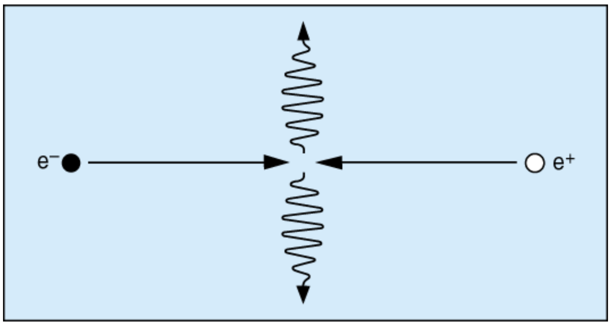
Process to obtain the energy spectrum of a radiation. The pulses of a detector supplying output pulses proportional to energy are sorted and counted according to their amplitude. The energy spectrum can be derived from the pulse amplitude distribution obtained in this way.

Amplitude analyzer

Device taking advantage of amplitude analysis to represent the energy spectrum of a radiation.

Annihilation radiation

Upon the collision of a particle and an anti-particle, e.g. electron and positron, these are „annihilated" as particles and the mass of these particles converted into energy. Electron and positron have a rest mass which is together equal to an energy of 1.02 MeV. Upon the „annihilation" of both particles, two gamma quanta of 0.511 MeV each are generated.



Occurrence of annihilation radiation upon collision of electron and positron. Two gamma quanta of 0.511 MeV each result.

Annual limit on intake (ALI)

The intake in the body by inhalation, ingestion or through the skin of a given radionuclide in a year which would result in a committed dose equal to the relevant dose limit.

Annular gap

Clearance between the two parts of a double containment kept under negative pressure. In the case of leaks in the inner containment, radioactive substances entering the annular gap are aspirated and either repumped or filtered and discharged via the vent stack in a controlled way.

Anticoincidence circuit

Electronic circuit which only supplies an output pulse when a pulse occurs at one - mostly predetermined - input. No output pulse is sent if pulses occur simultaneously at other inputs or are delayed by a certain period.

Antimatter

Matter in which the core particles (neutrons, protons, electrons) are replaced by the corresponding antiparticles (antineutrons, antiprotons, positrons).

Antiparticles

Antiparticles have the same mass, the same average life and the same spin as the corresponding particles, but opposite and equal baryon and lepton numbers. Antiparticles and particles are either both electrically neutral or they have an equal electric charge, but opposite signs.

	Particle: Proton	Antiparticle: Antiproton
Mass	$1.6726 \cdot 10^{-27}$ kg	$1.6726 \cdot 10^{-27}$ kg
Average life time	Stable	Stable
Spin	1/2 ħ	1/2 ħ
Baryon number	+1	-1
Lepton number	0	0
Electric charge	$+1.6022 \cdot 10^{-19}$ C	$-1.6022 \cdot 10^{-19}$ C

Key data for the proton/antiproton particle/antiparticle pair

Argonaut

Argonne Nuclear Assembly for University Training; type of training reactor.

ASME

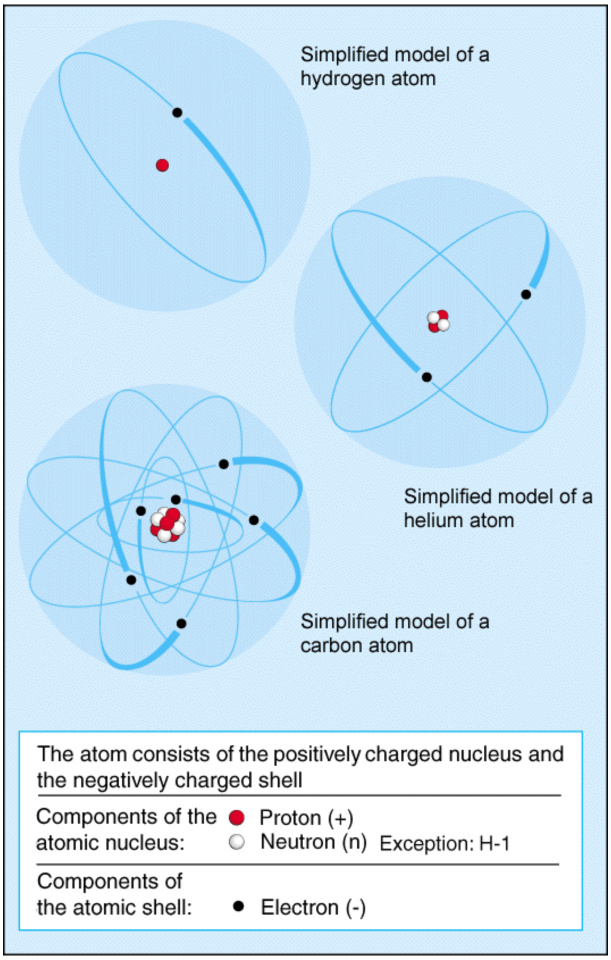
American Society of Mechanical Engineers, New York, N.Y., USA.

Asse

Former rock-salt mine 10 km to the south-east of Wolfenbüttel built for the trial ultimate waste disposal of low and medium active waste. More than 120 000 barrels equal to around 24 000 m^3 of low active waste have been stored here. A special storage chamber for medium active waste holds 1289 barrels of 200 l capacity. The storage licence for radioactive waste expired in 1978.

Atom

Smallest particle of an →element which cannot be chemically divided any further. The elements differ by their atomic structure. Atoms are inconceivably small. A normal drop of water contains about 6 000 quintillion (a 6 with 21 zeros) atoms. The diameter of an atom consisting of a nucleus and orbiting electrons amounts to approx. one hundred millionth of a centimetre (10^{-8} cm). The nucleus is made up of positively charged →protons and electrically neutral →neutrons. It therefore has a positive charge. Its diameter amounts to some ten trillionths of a centimetre (1 to $5 \cdot 10^{-13}$ cm). The nucleus is therefore 100 000 times smaller than the surrounding sheath of orbiting negatively charged →electrons which are as many as the protons in the nucleus. Atoms therefore behave electrically neutral to the outside. →nuclide



Atom model

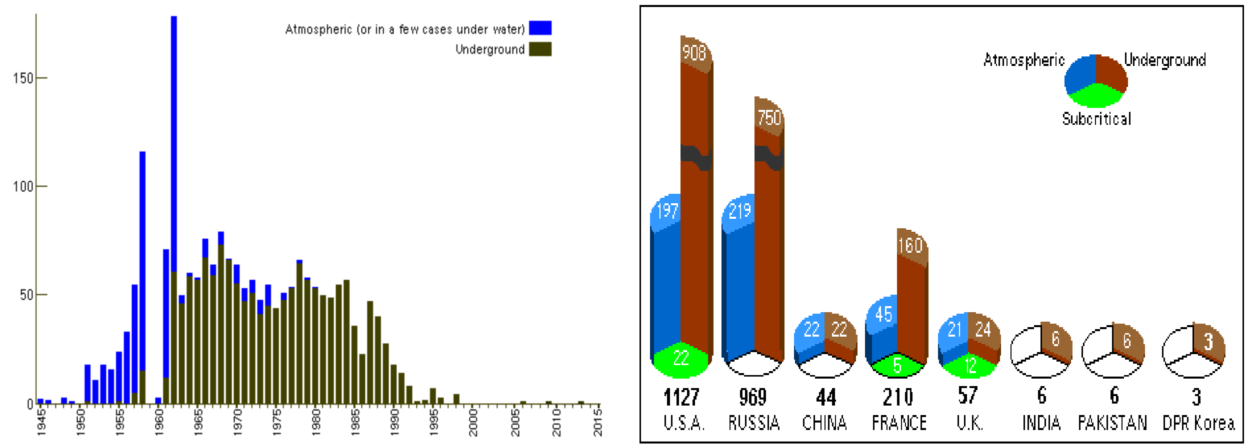
Atomic bomb

Nuclear weapon using the energy released during the fission of U-235 or Pu-239. The explosive force of a nuclear weapon is indicated in kilotonnes (kt) or megatonnes (Mt) of TNT equivalents (TNT (trinitrotoluol) is a chemical explosive). The bombs dropped on Hiroshima (U-235 bomb) and Nagasaki (Pu-239 bomb) had an explosive energy equal to 13 and 22 kt TNT. In each case about 1 kg fission material was fissioned in one millionth of a second. A minimum mass of fission material is required for a nuclear blasting charge, e.g. 52 kg of U-235. The highly developed weapon technology in the nuclear weapon countries partly enables lower values, e.g. 15 kg and less for metallic U-235. An ignition device is also required to shoot these fission materials together to a →critical configuration within a very short period so as to initiate the chain reaction. Experts quote a velocity of some kilometres per second for weapon plutonium and a multiple of this impact velocity is necessary for reactor plutonium with its high share of other plutonium isotopes. →hydrogen bomb

Type of fission material	Quantity in kg	
	as a metal	as an oxide
Weapon plutonium	10	30
Reactor plutonium	>13	40
93% enriched U-235	52	100
4 % enriched U-235 (LWR fuel)	not possible	not possible
U-233	16	40

Estimated minimum quantity of fission material for nuclear blasting charges

According to UNSCEAR 504 atmospheric explosion (plus 39 safety tests) and 1879 underground explosions were carried out till mid of February 2013.



Nuclear explosions by year and country

Atomic clock

Device to measure time intervals using nucleus or molecular oscillations. These oscillations are extremely constant in time.

Atomic number

Number of protons in an atomic nucleus. Each chemical element is determined by its atomic number. The arrangement of elements according to increasing atomic numbers forms the basis of the classification of elements.

Atomic weight

Relative number for the mass of an atom. The atomic weight scale is based on the carbon atom with a nucleus made up of six protons and six neutrons. It was allocated the atomic weight 12. Thus, the atomic weight unit is 1/12 of the weight of carbon-12. The atomic mass unit u is equal to $1.66053873 \cdot 10^{-27}$ kg.

ATWS

Anticipated Transients Without Scram.

Autoradiolysis

Dissociation of molecules through ionized radiation from radioactive materials contained in the substance or the substance mixture itself. Example: autoradiolytical dissociation in liquid high active waste.

Autoradiogram

Photographic record of the distribution of a radioactive material in a substance due to the radiation emitted by this material.

Availability factor

Measure of the ability of power plants, a unit or a plant section to perform its operational function. A distinction is to be made between equipment availability and energy availability:

- Equipment availability is the ratio of available time (operating and standby time) to the calendar period. Equipment availability characterizes the reliability of a plant.
- Energy availability is the ratio of available energy to theoretically possible energy in the period under report. Characterizes the reliability of a plant in general considering all complete and partial outages.

AVM procedure

French vitrification procedure for liquid high active waste. A plant has been operating in Marcoule/France since July 1978. This method is used on an industrial scale in the La Hague reprocessing plant. →vitrification

AVR

Experimental nuclear power plant, Jülich; high-temperature reactor with a gross electrical output of 15 MW. Nuclear commissioning on 26th Aug. 1966, final shutdown on 1st Dec. 1988. The cumulated power generation amounted to 1.7 TWh. The reactor was built according to the concept of a pebble-bed reactor developed by Prof. Schulten. The AVR was primarily used to gain operating experience for the development of high-temperature reactors. The AVR was the first power reactor completely developed in Germany.

B

Barn

Unit used in nuclear physics to indicate →activation cross-sections of particles for a certain reaction. Symbol: b. One barn is equal to 10^{-28} m²; this is approx. the cross-section area of a nucleus of an atom.

Barrier

The safe enclosure of the radioactive inventory of a nuclear plant is structured according to the multiple barrier principle, i.e. radioactive substances must pass these multiple different barriers connected in series before they are released. Barriers of a nuclear reactor:
- Retention of the fission products in the nuclear fuel itself,
- Enclosure of the nuclear fuel in cladding tubes,
- Enclosure of the fuel elements in the reactor pressure vessel and primary coolant system,
- Gas-tight containment around the reactor pressure vessel.

Baryon

Elementary particle with the baryon number 1, this means: neutron, proton, hyperon. The name (βαρύς (barys), Greek for "heavy") is derived from the relatively large mass of these particles compared to other elementary particles (→leptons, →mesons). →elementary particle

Base load power plants

Power plants for electricity supply which due to their operational and economic properties are used to cover the base load and are operated at high capacity operating hours. Base load power plants are run-of-river, lignite-fired and nuclear power plants. →load ranges

Becquerel

Unit of activity of a radionuclide named after Henri Becquerel who first discovered radioactivity. Symbol: Bq. The activity is equal to 1 Becquerel if 1 nucleus decays per second in the present quantity of a radionuclide. The unit replaces the former unit curie. →curie

BEIR

Committee on the Biological Effects of Ionizing Radiation; a committee of the National Research Council of the USA which publishes a series of reports informing the US government on the effects of ionizing radiation. The BEIR Committee published the following reports:

BEIR III 1980: "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation";
BEIR IV 1988: "Health Effects of Radon and Other Internally Deposited Alpha-Emitters";
BEIR V 1990: "Health Effects of Exposure to Low Levels of Ionizing Radiation";
BEIR VI 1999: “The Health Effects of Exposure to Indoor Radon",
BEIR VII, Phase 1 1998: “Health Risks from Exposure to Low Levels of Ionizing Radiation, Phase 1“,
BEIR VII, Phase 2 2006: “Health Risks from Exposure to Low Levels of Ionizing Radiation, Phase 2.

BER II

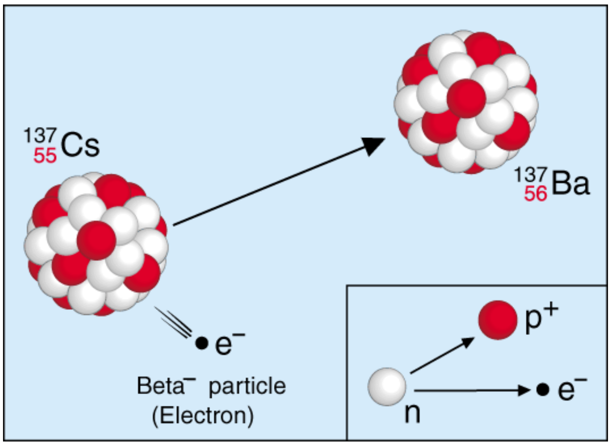
Research reactor of the Helmholtz Centre Berlin for Materials and Energy. BER II is a pool reactor with a thermal output of 15 MW, commissioned on 9th Dec. 1973.

Beta decay

Radioactive conversion emitting a →beta particle. During beta decay the mass number of the parent nuclide is equal to the newly created nuclide, the atomic number changes by one unit; namely the atomic number during beta decay emitting a positron - →beta-plus decay - becomes by one unit smaller and during beta decay emitting a negative electron - →beta-minus decay - by one unit greater.

Beta-minus decay

Radioactive conversion emitting a negative electron ($ß^-$ particle), e.g. decay of P-32 into S-32 or Cs-137 into Ba-137.



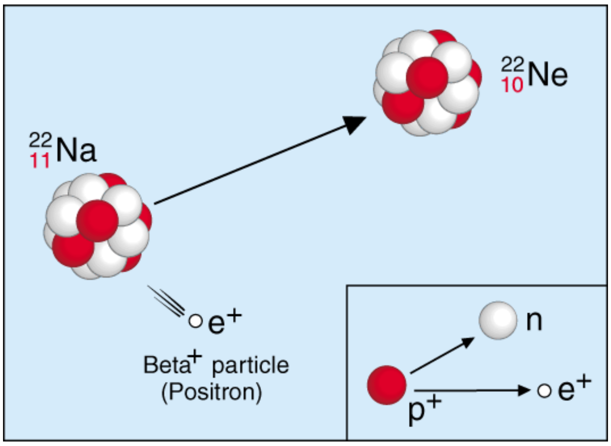
Beta-minus decay (beta$^-$ decay, β^- decay). Decay of Cs-137 into Ba-137 emitting an electron (beta$^-$ particle, β^- particle)

Beta particle

Electron with positive or negative charge emitted by a nucleus or elementary particle during beta decay. Depending on the charge of the emitted electron this is also called beta-plus radiation ($ß^+$ radiation) and beta-minus radiation ($ß^-$ radiation).

Beta-plus decay

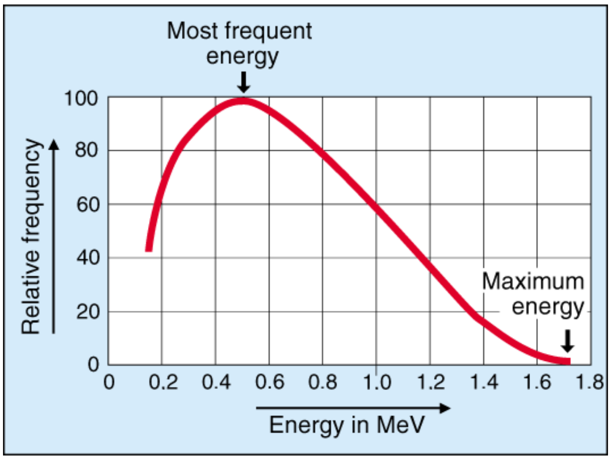
Radioactive conversion emitting a positron ($ß^+$ particle), e.g. decay of Na-22 into Ne-22.



Beta-plus decay (beta$^+$ decay, β^+ decay); decay of Na-22 into Ne-22 emitting a positron (beta$^+$ particle, β^+ particle)

Beta radiation

Beta radiation is the emission of electrons or positrons during the radioactive decay process. Beta radiation has an energy continuum. The maximum energy $E_{ßmax}$ is always quoted, e.g. for P-32 decay this is 1.7 MeV. Beta radiation is already absorbed by thin layers (e.g. plastic or 1 cm aluminium).



Energy distribution of the electrons (β^- particles) emitted during the β^- decay of P-32

Betatron

Device to accelerate electrons to energies of some ten MeV. The electrons run in an annular vacuum tube and are kept on this orbit by a magnetic field array. They are accelerated by electromagnetic induction (transformer principle).

BfS

Bundesamt für Strahlenschutz, i.e. →Federal Office for Radiation Protection.

Biblis A

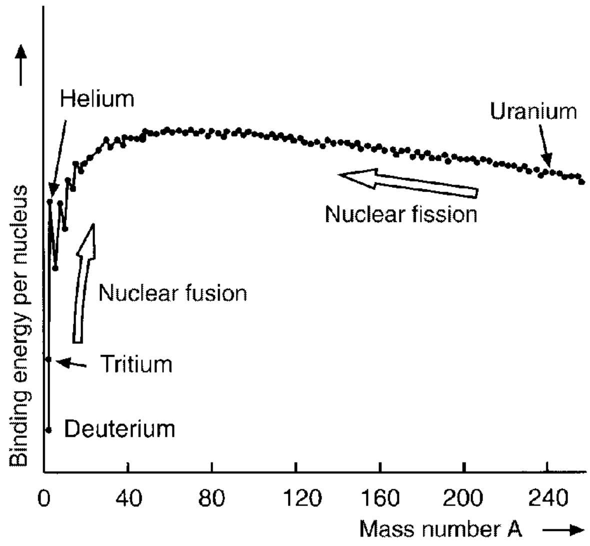
Nuclear power plant Biblis/Rhine, unit A, pressurized water reactor with a gross electrical output of 1 225 MW, nuclear commissioning on 16th April 1974, final shutdown on 6th August 2011, application for decommissioning on 6th August 2012, lifetime electricity generation 232,8 TWh.

Biblis B

Nuclear power plant Biblis/Rhine, unit B, pressurized water reactor with a gross electrical output of 1 300 MW, nuclear commissioning on 25th March 1976, final shutdown on 6th August 2011, application for decommissioning on 6th August 2012, lifetime electricity generation: 247,4 TWh.

Binding energy

The energy required to separate connected particles (infinitely far apart). In the case of the nucleus of an atom, these particles are protons and neutrons held together by the nuclear binding energy. The neutron and proton binding energies are the energies necessary to release a neutron or proton from the nucleus. Electron binding energy is the energy required to completely remove an electron from an atom or a molecule. The binding energy of nucleons in the nucleus of an atom amounts for most nuclei to around 8 MeV per nucleon. In the case of the heaviest nuclei of an atom, such as uranium, the binding energy per nucleon is clearly lower than for nuclei with medium mass numbers. Therefore, the fission of an uranium nucleus into two nuclei of medium mass number results in a total higher binding energy leading to energy being released to the outside (→nuclear fission). The binding energy of the light nuclei of the hydrogen isotopes deuterium and tritium is significantly lower than that of the helium nucleus He-4. Thus, energy is released during the fusion of deuterium and tritium to helium (→fusion).



Nucleus binding energy per nucleon as a function of the mass number

Biosphere

Sphere of life for all organisms on earth; it reaches only a few meters down into the ground, except for bacteria, several kilometres up in the air and down to the deepest point in water.

Blanket

Reactor zone containing →fertile material for breeding.

BMBF

Bundesministerium für Bildung und Forschung, i.e. Federal Ministry for Education and Research.

BMU

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, i.e. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Body burden

The body burden is the activity of a certain radionuclide in a human or animal body.

Body counter

Device to measure activity and identify incorporated radionuclides in the human body.

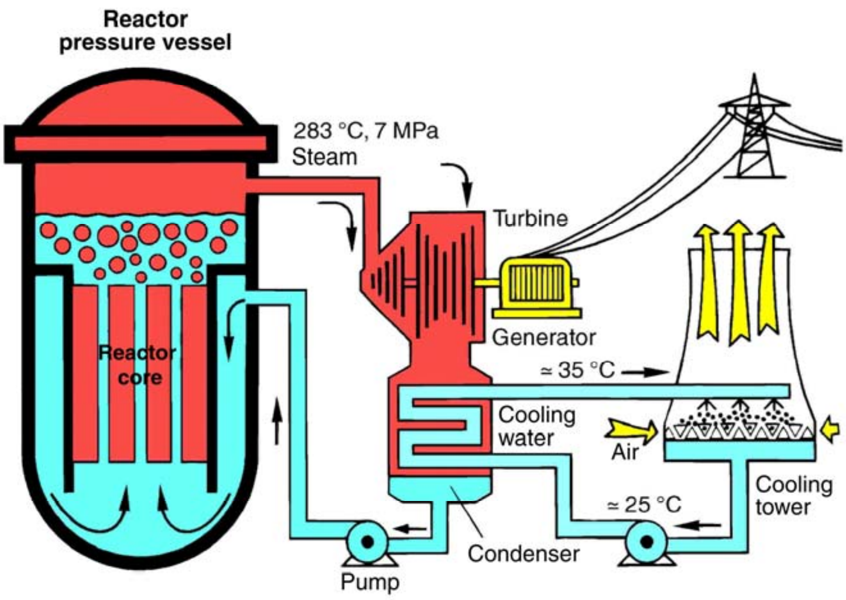
Body counter of the Karlsruhe Institute of Technology (KIT) to determine the gamma-radiating radionuclides in the human body

Body dose

Body dose is the general term for effective →dose and →organ dose. The body dose for a reference period (e.g. calendar year, month) is the sum of the body dose received by external radiation exposure during this period of time and the →committed dose which is conditional on an activity intake occurring during this period.

Boiling water reactor

Nuclear reactor with water as a coolant and as a moderator, boiling in the core. The resulting steam is generally used directly to drive a turbine. Example: Example: Nuclear Power Plant Gundremmingen, Unit C, 1,344 MWe. The fuel elements containing the uranium dioxide are located in the pressure vessel, two thirds of which are filled with water. The water flows through the core from bottom to top and removes the heat developed in the fuel elements. Part of the water evaporates. Following steam-water separation in the upper part of the pressure vessel, the saturated steam at a temperature of about 290 °C and a pressure of approx. 70 bar (7 MPa) is fed to the turbine. This amounts to up to 7,500 t steam per hour. The turbine is coupled to a three-phase generator. The steam exiting the turbine is liquefied in the condenser. For this purpose about 160,000 m^3 cooling water per hour is required and is taken from the cooling tower circuit. The feed water is heated to a temperature of about 215°C by means of a heating system and refed into the reactor. The control rods containing the neutron-absorbing material are inserted in the core from below by means of an electromotor (normal drive) or hydraulically (trip). The piping leads out of the containment into the engine house. A number of safety devices are installed to achieve immediate isolation of the reactor from the engine house in case of a malfunction.



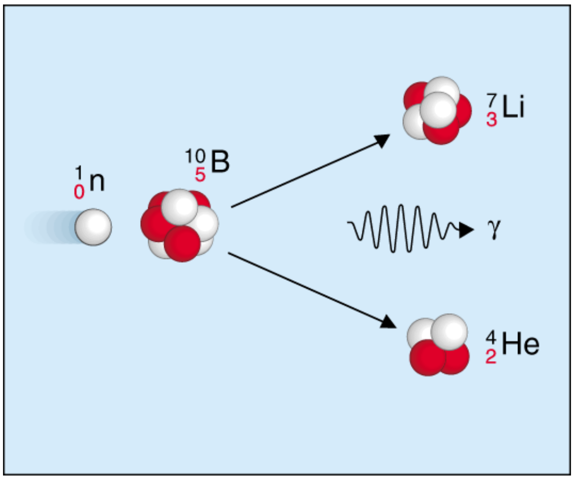
Principle of a nuclear power plant with boiling water reactor

Bone seeker

A substance preferably deposited in bones in the human and animal body. In the case of radioactive substances e.g. Sr-90 or Ra.

Boron counter

Detector, e.g. proportional counter tube, containing gaseous BF_3, used to detect slow neutrons where the alpha particle generated in the chain reaction of the neutron with B-10 serves as proof of neutrons.



Borosilicate glass

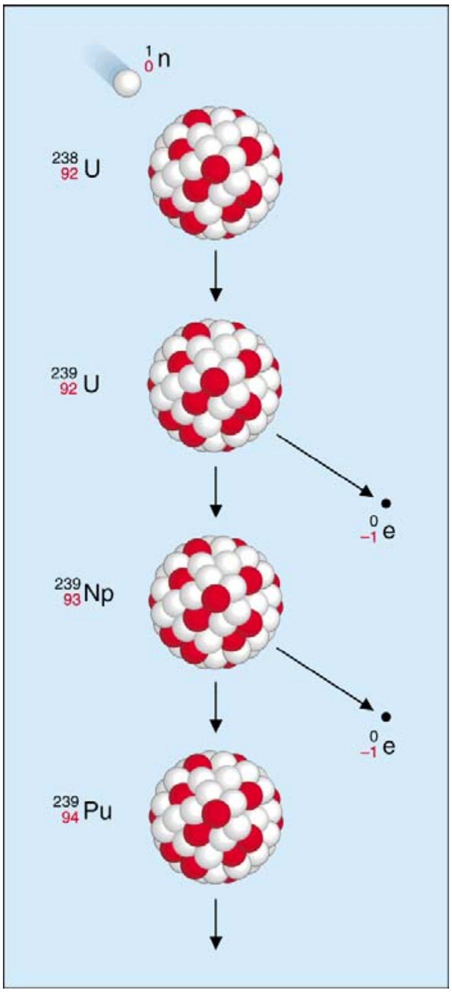
Type of glass with high →resistance to leaching, suitable to solidify liquid high active waste from nuclear fuel reprocessing. →vitrification

Bq

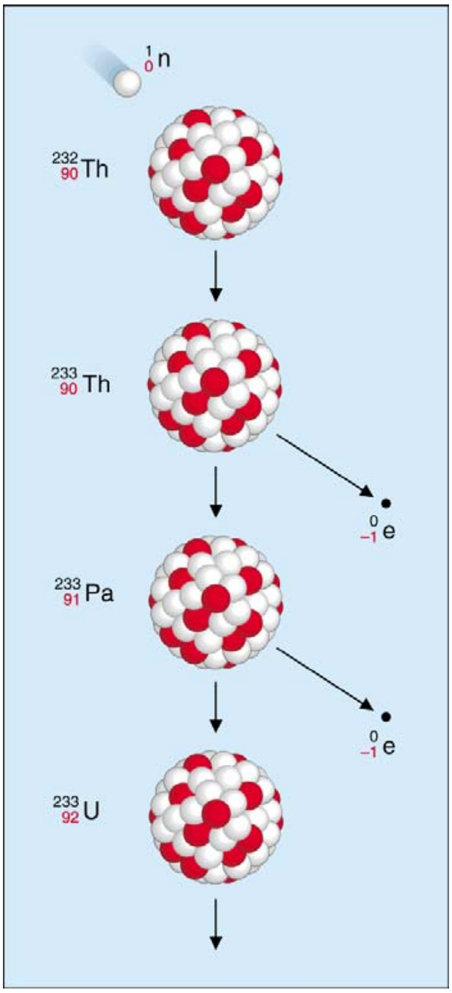
Symbol for →becquerel, the name of the unit for activity.

Breeding

Conversion of non-fissionable into fissionable material, e.g. uranium-238 into plutonium-239 or thorium-232 into uranium-233. Neutron radiation in a reactor produces uranium-239 from uranium-238 by neutron capture; uranium-239 converts into plutonium-239 following two subsequent beta decays.



Breeding process: generation of Pu-239 from U-238



Breeding process: generation of U-233 from Th-232

Breeding factor

→breeding ratio

Breeding gain

Excess fissile material produced in a reactor compared to the fissile material quantity spent, relative to the used quantity. The breeding gain is equal to the →breeding ratio minus 1.

Breeding process

The conversion of non-fissionable material into fissionable material. →fertile material.

Breeding ratio

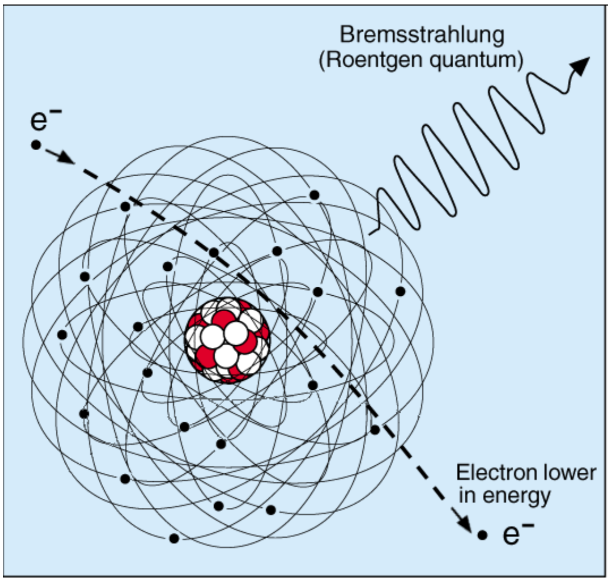
The ratio of →fissile material obtained to spent fissile material after the use of a fuel mixture of fissile and fertile material in a reactor.

Breeding reactor

A reactor generating more fissile material than it uses. →converter reactor, →fast breeder

Bremsstrahlung

Electromagnetic radiation generated when electrically charged particles are accelerated or decelerated. The spectrum of emitted radiation reaches from a maximum energy given by the kinetic energy of the generating particle down to zero energy. Bremsstrahlung only becomes easily noticeable when the energy of the particle is very high compared to its rest-energy. This is mostly only valid for electrons (rest-energy of the electron: 511 keV).



Generation of bremsstahlung when decelerating an electron which interacts with an atom

Bubble chamber

Device to proof and measure nuclear radiation. In an overheated liquid (mostly liquid hydrogen) charged particles generate a trail of tiny steam bubbles along their orbit which can be photographed and then evaluated.

Build-up factor

→dose build-up factor

Burnup

In contrast to fossil fuel the fuel in nuclear reactors cannot be converted "in one go" since the fuel undergoes changes during its use in the reactor which require the →fuel elements to be exchanged. The fuel which has not been spent and the generated plutonium may be recovered by →reprocessing the removed fuel elements. Light water reactors have a burnup of 45 000 to 50 000 MWd/t of uranium. This means that about 45 to 50 kg of fissionable material per tonne of nuclear fuel used have been fissioned and 360 to 400 million kWh of electricity have been generated at a nuclear power plant efficiency of 34%.

BWR

→boiling water reactor

C

C-14

→Carbon-14

Calder Hall

The world's first commercial nuclear power plant in Seascale, England. The Calder Hall Nuclear Power Plant consists of four gas-graphite reactors, each with an electrical power of 55 MW. First connection to the grid on August 27, 1956. Final shutdown due to commercial reasons March 31, 2003.

CANDU

Canadian heavy-water-moderated pressure tube natural uranium reactor. The name is made up of: "CAN“ for Canada, "D" for the technical term deuterium oxide i.e. heavy water and "U" for the uranium fuel.

Canister

In nuclear technology the designation for the glass block - including its gas-tight welded metal casing made of corrosion-resistant steel - of vitrified high active waste. A canister contains about 400 kg of glass product with 16% radioactive waste.

Capacity factor

Ratio of available capacity to theoretically possible capacity in the period under report. Characterises the reliability of the plant. →availability factor

Capacity operating hours

The capacity operating hours of a nuclear power plant are equal to the quotient from the total capacity in a period of time and the maximum capacity of the plant. The capacity operating hours of various power plants for public supply in Germany in 2009 amounted to:

- Photovoltaic 890 h/a
- Pumped storage hydroelectric 950 h/a
- Wind 1,520 h/a
- Mineral oil 1,870 h/a
- Natural gas 3,150 h/a
- Run-of-river hydroelectric 3,530 h/a
- Hard coal 3,580 h/a
- Biomass 5,000 h/a
- Lignite 6,610 h/a
- Nuclear 7,710 h/a

Carbon-14

Natural carbon-14 (C-14) is generated by a (n,p)-reaction of neutrons of cosmic radiation with nitrogen -14 in the upper atmosphere. Measurements of wood from the 19th century resulted in about 230 becquerel C-14 per kilogram carbon. This natural (pre-industrial) ratio between the radioactive carbon-14 and the stable carbon-12 in the atmosphere is today influenced by two opposed effects:

- The massive generation of CO_2 by burning fossil C-14-free energy carriers leads to an increase in the proportion of C-12. Thus the pre-industrial ratio of C-14 to C-12 is reduced. In the mid-50s, this so-called Suess effect resulted in a five percent reduction of C-14 activity per kg carbon in the atmosphere.
- Nuclear weapon tests in the atmosphere and disposal from nuclear facilities cause the proportion of C-14 in the atmosphere to increase.

The natural concentration of C-14 leads in the human body to a C-14-activity of about 3 kBq. The resulting effective dose amounts to 12 µSv/year.

Castor

Cask for **s**torage and **t**ransport **o**f **r**adioactive material. Type of container for the transport and interim storage of spent fuel elements and vitrified high active waste. All CASTOR® types have the same basic concept. The transport container is a thick-walled (approx. 450 mm) body of cast iron with spheroidal graphite. This material is characterized by its extremely high strength and toughness. The cast body wall is provided with through axial boreholes filled with plastic rods. These plastic inserts are used as a neutron shield. The bottom and cover also have such inserts. The fuel elements are held in a rack of boron steel, a neutron absorbing material. The container is closed by a multiple cover system. This consists of an approx. 340 mm thick primary cover and an approx. 130 mm thick secondary cover made of special steel. The two overlying covers are bolted firmly to the container body. The sealing effect of the covers is ensured by special metallic packings. A protective steel plate screwed over the cover system protects this against mechanical impacts and humidity. Lifting lugs are attached to the top and bottom of the container. The safety of the fuel element containers of the CASTOR® type was verified by the following tests:

- A drop from a height of 9 m onto a practically inflexible foundation (concrete base of 1 000 t, covered with a 35 t heavy steel plate). These crash tests were partly carried out with containers cooled to minus 40 °C. The material is less resistant at this low temperature. During the crash tests from 9 m height onto the practically inflexible concrete-steel base the containers are subjected to loads which are extremely unlikely during actual transport. Therefore, the tests are representative for a crash from far higher altitudes onto a real base, e.g. a street or ground and for loads occurring in the most serious traffic accidents.
- Fire tests at a temperature of more than 800 °C for half an hour,
- Simulation of an aircraft crash by bombardment with a missile weighing approx. 1 t at almost sonic speed.

CEA

Commissariat à l’énergie atomique et aux énergies alternatives, (Atomic Energy and Alternative Energies Commission)

Centrifuge

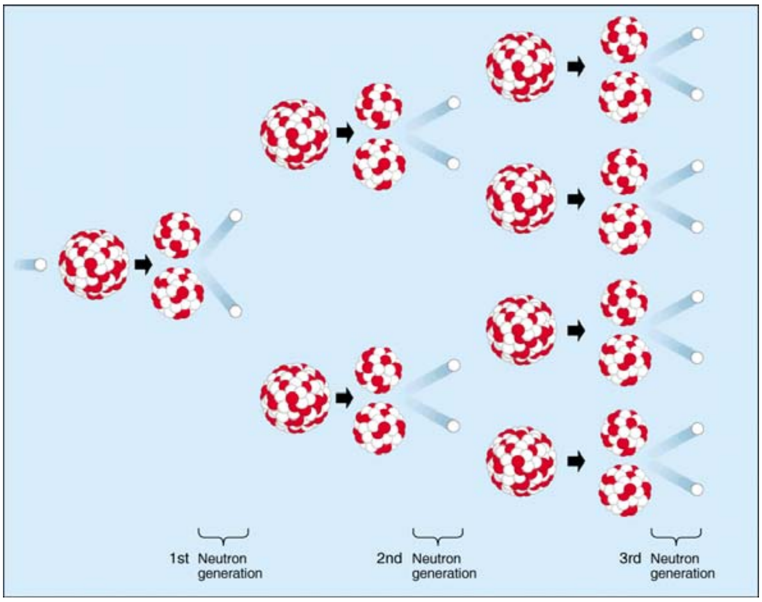
→gas centrifuge process

Čerenkov radiation

Light with a maximum of intensity in the blue spectral region, created when charged particles move in a translucent medium at a speed v, this being greater than the speed of light in this medium ($v > c_0/n$, c_0 = speed of light in a vacuum, n = refractive index). The threshold energy for the occurrence of Čerenkov radiation for electron radiation in water (n = 1.33) amounts to 260 keV.

Chain reaction

Self-perpetuating reaction. In a fission chain reaction, a fissile nucleus absorbs a neutron, splits and simultaneously releases several neutrons (in the case of U-235 an average of 2.46). These neutrons can be absorbed in turn by other fissile nuclei, initiate fissions and release other neutrons.



Principle of a chain reaction

Chernobyl

At the Chernobyl location, 130 km north-west of Kiev, four reactor units of type RBMK-1000 entered service between 1977 and 1983. On 26th April 1986, the most serious accident to date in the peaceful use of nuclear energy occurred in unit 4. Although the accident at the Chernobyl Nuclear Power Plant was due to a series of wrong decisions and forbidden interventions by the operating staff, it was the inefficient reactor safety concept and the lack of a pressure-tight containment enclosing the reactor plant which were ultimately responsible for the occurrence of the accident and the release of such large quantities of radioactive substances. The reactor accident developed during an experiment with the turbine generator set of the power plant. A number of operating mistakes including the bridging of shutdown signals entailed a major power increase - up to 100 times the nominal power. The overheating of fuel caused the rupture of fuel rod claddings, resulting in a heavy fuel/water reaction with shock-like pressure build-up and destruction of the reactor building. Considerable sections of the graphite moderator and the plant were set on fire. During the destruction phase, approximately eight tonnes of radioactive fuel from the core were hurled into the building and the environment. Thanks to the immediately initiated fire fighting, it was possible to extinguish the fires outside the reactor building and in the engine house within four hours. To smother the moderator graphite fire in the reactor and limit the consequences of the accident, unit 4 was filled in by air with a total of 5 000 tonnes of lead, sand and clay in the following days. By November 1986, the Chernobyl reactor unit 4 stayed „buried" under a structure of metres of concrete - called sarcophagus.

The massive release of radioactive fission products from the destroyed reactor continued for more than ten days. Due to the thermal lifting effects the release, in particular that of the volatile fission products such as iodine and caesium, took place up to considerable altitudes (1 500 m and more). This led to dispersion of the activity of $4 \cdot 10^{18}$ Bq released into the atmosphere over broad areas of Europe. The radioactive substances released on 26th April reached Sweden on 28th April due to the prevailing north-west wind. The activity increase measured there in the air was the first indication of the accident in the west. Because of the weather conditions, the activity emission of the 27th April reached Poland and that of the 29th and 30th April reached Central Europe via the Balkans. On 29th April the radioactive cloud reached the territory of the Federal Republic of Germany.

The power plant personnel and in particular the fire-fighting staff were seriously affected by radiation. The dose values amounted up to 16 Gy. 203 persons with acute radiation syndrome were treated in hospitals. 31 persons died as a result of burns and radiation overexposure. The radiation exposure in the town of Pripyat 4 km to the west of the location with 45 000 inhabitants amounted to up to 6 mSv/h on the day after the accident. The population was subsequently evacuated. In the following days, a further 90 000 persons were evacuated from the 30-km zone around the location. A resettlement of the 10-km zone is not intended; the agricultural use of the 10- to 30-km zone depends upon the success of decontamination programmes and the result of radiological examinations.

Due to meteorological influences, the activity quantities from the radioactive cloud deposited in the regions of the Federal Republic are quite different - in the north and west clearly less than in the south and south-east. Therefore, no uniform values for the resulting radiation dose in Germany are possible, which also depends considerably on the individual dietary habits. The inhalation dose was almost exclusively determined by the aerial activity between 1st and 5th May 1986. The ingestion dose results almost exclusively from I-131, Cs-134 and Cs-137. The radiation exposure in the following years was remarkably lower than in the first year after the accident.

person group	period	North	South	foothills of the Alps
		effective dose, mSv		
infants	1986	0.12	0.35	0.6
	lifetime	0.4	1.3	2.4
adults	1986	0.1	0.3	0.5
	lifetime	0.4	1.1	2.1

Average radiation exposure due to the Chernobyl accident in different areas of Germany

For individual persons with extreme living and eating habits, maximum dose values of up to twice or three times of these values may result.
In the areas of the Ukraine and Belarus affected by the accident, children and young adults showed a considerable increase in thyroid gland cancer in the following years, which is to be explained by the radiation exposure. Above all the intake of iodine-131, a radioactive isotope with a half-life of about 8 days, via the nutrition chain and its storage in the thyroid gland led to high radiation doses in this organ. In the countries concerned, more than one thousand thyroid gland cancer cases have occurred to date in children and young people. Based on the risk observations, a total of up to 4 000 thyroid gland cancer cases are expected.
Unit 2 of the four reactor units at the Chernobyl location was finally shutdown in October 1991. Unit 1 followed in November 1996. On 15th December 2000 unit 3, the last reactor in Chernobyl, was finally shutdown.

Chop and leach

Procedure in reprocessing plants to break up the fuel rods. The irradiated fuel rods are cut into pieces a few centimetres in size using a mechanical device and the nuclear fuel and fission products are then leached from the fuel element cladding tubes using nitric acid in a dissolving tank.

Chromatography

Procedure to separate substances from substance mixtures where the distribution processes occurring between a stationary and a mobile phase (mobile solvent) have a separating effect. One differentiates between column, paper and thin-layer chromatography depending on the arrangement of the stationary phase.

Ci

Unit symbol for →curie.

Cladding

Tight cladding directly surrounding the nuclear fuel which protects it against a chemically active ambience (cooling water) and prevents the escape of fission products into the cooling water.

Classification of elements

System of elements according to rising atomic number. Classification in „periods“ in accordance with the electron configuration of the atomic shell. The chosen classification system shows chemically similar elements in „groups“ (main groups and sub-groups) below one another.

Closed-circuit cooling systems

Cooling tower (wet; dry; forced-air ventilation; natural draught) or cooling pond to cool the heated cooling water of a power plant prior to feedback into the cooling circuit to reduce fresh-water consumption for cooling purposes.

Closed-circuit ventilation

Coolant (water) circulating in a circuit for heat removal. The heat is dissipated via a cooling tower.

Cloud chamber

Device making the path of electrically charged particles visible. It consists of a chamber filled with oversaturated steam. If charged particles pass through the chamber they leave a cloud track. The track makes an analysis of the movements and interactions of the particles possible. →bubble chamber, →spark chamber

Coal equivalent

Reference unit for the energetic evaluation of various energy carriers. 1 kg coal equivalent corresponds to a value specified as 7 000 kilocalories (7 000 kcal ≈ 29.3 MJ ≈ 8.141 kWh) and thus approximately the calorific value of hard coal which, depending on the type, amounts to between 29.3 MJ/kg (gas-flame coal) and 33.5 MJ/kg (anthracite).

1 kg gasoline	1.59 kg coal equivalent,
1 kg fuel oil	1.52 kg coal equivalent,
1 m^3 natural gas	1.35 kg coal equivalent,
1 kg anthracite	1.14 kg coal equivalent,
1 kg hard coal	1.00 kg coal equivalent,
1 kg hard coal coke	0.97 kg coal equivalent,
1 kg lignite briquette	0.72 kg coal equivalent,
1 m^3 town gas	0.60 kg coal equivalent,
1 kg firewood	0.57 kg coal equivalent,
1 kg fire peat	0.56 kg coal equivalent,
1 kg crude lignite	0.34 kg coal equivalent,
1 kWh	0.123 kg coal equivalent.

During the complete fission of 1kg U-235, 19 billion kilocalories are released, i.e. 1 kg uranium-235 corresponds to 2.7 million kg coal equivalent.

Coated particles

Fuel grains consisting of highly enriched UO_2 or mixtures of UO_2 and ThO_2, surrounded by a practically gastight envelope of pyrolytically precipitated carbon. They are used as fuel elements in a graphite matrix in high-temperature reactors.

Cogeneration

Simultaneous generation of electricity and process or district heat in a power plant. Cogeneration achieves a higher overall thermal efficiency than power generation alone. The prerequisite for cogeneration is a high demand of heat in the vicinity of the power plant. The Nuclear Power Plant Stade supplies process steam to a chemical factory in the immediate vicinity.

Coincidence

Occurrence of two events at the same time. Coincidence does not mean that two events occur absolutely simultaneously, but that both events occur within a period given by the temporal resolution capacity of the detection device.

Collective dose

Product of the number of persons of the exposed population group and the average dose per person. The „man-sievert" is the usual unit for the collective dose.

Commission on Radiological Protection

Pursuant to the statutes of the Commission on Radiological Protection (SSK - Strahlenschutzkommission) dated 8th August 2012, the SSK's task is to advise the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in matters relating to the protection of hazards resulting from ionizing and non-ionizing radiation. In detail, the SSK's task comprises the following subjects:

- radiation effects and dose-effect-relationships,
- proposals for dose limits and derived limits,
- monitoring the exposure of the population, special population groups and workers,
- guidelines and special measures of protection against hazards arising from ionizing and non-ionizing radiation,
- guidelines on emergency preparedness and measures to reduce the radiation exposure in the event of a nuclear emergency or catastrophe,
- dispersion models for airborne and liquid releases of radionuclides from licensed facilities,
- the consequences of international recommendations on the German system of radiological protection,
- development and scientific support of research programmes on radiological protection topics.

In accordance with its statutes the SSK can form committees and working groups for special task and determine their missions in agreement with the competent federal ministry or upon its request.

Committed dose

The irradiation of tissue or organs with incorporated radionuclides is distributed over the incorporation period. This period depends on the physical half-life and the biokinetic behaviour of the radionuclide. The committed dose is equal to the time integral of the dose rate in a tissue or organ over the time. The integration period for calculation of the committed dose amounts to 50 years for adults and to 70 years for children.
The organ committed dose $H_T(\tau)$ for an incorporation at the time t_0 is the time integral of the organ dose rate in the tissue or organ T:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)dt \, .$$

where

$\dot{H}_T(t)$	is the average organ dose rate in the tissue or organ T at the time t
τ	period in years over which the integration is effected. If no value is indicated for τ, a period of 50 years for adults and the period from the respective age to the age of 70 years for children are taken as a basis.

Compact storage basins

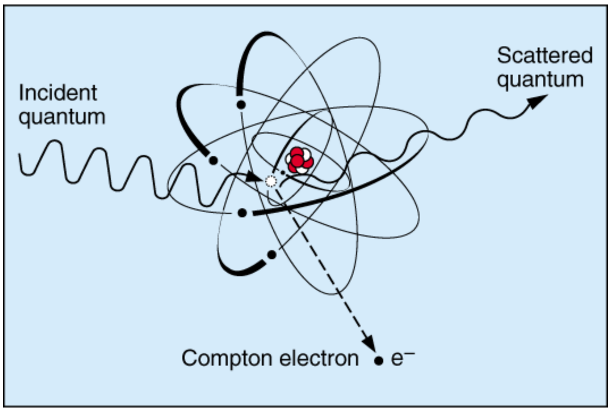
Facility to store irradiated fuel elements in the reactor building placing more elements in the storage basins - compared to normal storage - applying technical measures to maintain criticality safety.

Company for Industrial Plants and Nuclear Safety

The GRS - Gesellschaft für Anlagen- and Reaktorsicherheit mbH - is a scientific non-profit-making company financed by public means. Its task involves the evaluation and development of technical safety, primarily in the field of nuclear engineering: assessment of technical and operational safety, research and development as well as scientific consulting in safety-related issues. The GRS executes its tasks on the basis of knowledge and experiences from research and development, safety analyses and operational assessments with scientists from various areas of engineering, physics, chemistry, geochemistry, geophysics, mathematics, informatics, biology, legal science and meteorology. The GRS is situated in Cologne and has further offices in Garching near Munich, in Brunswick and in Berlin.

Compton effect

Interactive effect of x-ray and gamma radiation with matter. The Compton effect is the elastic scattering of a quantum with a free or quasi-free electron from the electron sheath of an atom. Part of the energy and the pulse of the quantum is transferred to the electron, the rest remains with the scattered quantum.



Compton effect, interaction of a gamma quantum with a sheath electron

Condensing basin

Water pool within the containment of a boiling water reactor to condense the escaping steam in the case of rupture of live steam piping. Condensing the steam reduces the high pressure within the containment.

Containment

Gastight case around a reactor and the circuit and auxiliary systems so that - even after an incident - no radioactive substances may escape into the atmosphere and environment. The containment is one of the barriers in a nuclear power plant that make it difficult for radioactive substances to escape into the environment. It surrounds the nuclear part of the plant and is designed so that in case of serious malfunctions it collects the exiting steam without failing itself. The containment of a pressurized water reactor is e.g. a steel ball with a diameter of approx. 50 m and a wall thickness of 30 mm. It includes rapidly closing valves in the pipings leading out of the containment and personal and material locks. The case is enclosed by an up to 2 m thick reinforced concrete dome to protect against external impacts. The inner wall of the dome is lined with a gas-tight steel skin. Negative pressure exists in the annular gap between containment and steel skin. The radioactive substances exiting the containment during normal operation enter the negative pressure zone and reach the vent stack via filters. During an incident, the air from the negative pressure zone is pumped back into the containment.

Contamination

Unwanted pollution of working surfaces, devices, rooms, water, air, etc. by radioactive substances. →decontamination

Control rod

A rod- or plate-shaped arrangement to control the reactivity variations of a nuclear reactor. The control rod consists of neutron-absorbing material (cadmium, boron, etc.).

Controlled area

Controlled areas are areas in which persons may receive an effective dose of more than 6 millisievert or higher organ doses than 45 millisievert for the eye lens or 150 millisievert for the skin, the hands, the forearms, the feet and ankles in a calendar year. In this context, the external and internal radiation exposure is to be considered. A period of 40 hours per week and 50 weeks per calendar year for remaining in a certain area is decisive for the determination of the limit for controlled area or monitoring area, if no other reliable data on time of staying is available. Controlled areas must be fenced off and identified. Access is permissible only with observation of special radiation protection regulations.

Convention on Third Party Liability in the Field of Nuclear Energy

Convention of 29th July 1960 on the third party liability in the field of nuclear energy (Paris Convention on Third Party Liability in the Field of Nuclear Energy), announcement of the amended version dated 15th July 1985 in the Federal Law Gazette, Part II, p. 963. International convention to ensure that persons who suffer damage from a nuclear incident receive adequate and fair compensation and simultaneously to take the measures necessary to ensure an unhindered development of the generation and use of nuclear energy for peaceful purposes.

Conversion coefficient, internal

Quotient of the number of emitted conversion electrons and the number of unconverted gamma quanta emitted.

Conversion electron

Electron released from the atomic shell by transferring the energy of a gamma quantum emitted from the same nucleus to this electron. The kinetic energy of the conversion electron is equal to the energy of the gamma quantum reduced by the binding energy of the electron.

Conversion

In nuclear technology the conversion of a substance in a fissile substance, e.g. uranium-238 ⇒ plutonium-239 or thorium-232 ⇒ uranium-233. →fertile material

Conversion, radioactive

A spontaneous nuclear conversion where particles are emitted or a sheath electron is captured, or spontaneous fission of the nucleus occurs.

Converter reactor

Nuclear reactor which generates fissile material, but less than it uses. This term is also used for a reactor that generates fissile material which differs from the spent fuel. In both meanings the process is called conversion. →breeding reactor

Coolant

Any substance used to remove the heat in a nuclear reactor. Usual coolants are light and heavy water, carbon dioxide, helium and liquid sodium.

Cooling pond

Use of artificial or natural ponds or lakes to recool the water. A power plant with an electric output of 1 300 MW needs a pond with a cooling surface of about 10 km^2 to be able to maintain a cooling water temperature of 21 °C at humid air temperatures of 8 °C (12 °C dry, relative humidity 57%).

Cooling tower

Tower-like concrete construction for →closed-circuit cooling. →wet cooling tower, →dry cooling tower

Core

Part of the nuclear reactor where the fission chain reaction takes place.

Core catcher

Core meltdown retention device, →core meltdown.

Core meltdown

If the reactor core cooling fails, e.g. due to a major leakage in the reactor cooling circuit, and the emergency core cooling system fails simultaneously, the residual heat in the fuel created by the radioactive decay of the fission products heats up the reactor core - possibly until the fuel melts. During the meltdown, the core support structures also fail so that the whole molten mass drops into the lower hemispherical area of the reactor pressure vessel. It can be assumed that the heat released by the molten mass melts through the bottom of the reactor pressure vessel. The density of the containment is important for the extent of radioactive substances released to the environment in the case of such a core meltdown accident.

Core meltdown retention basin

Construction in a reactor to collect and cool the molten reactor core. The reactor pit is designed to collect the liquid molten metal mass generated during a core meltdown accident and guided by gravity to a lower-level area made of refractory material over which the molten mass spreads and the energy contained in it can be removed by cooling and the molten mass solidifies.

Cosmic radiation

Radiation originating directly or indirectly from extraterrestrial sources. Cosmic radiation is part of natural radiation and its dose depends on the altitude above sea level. At sea level it amounts to 0.3 mSv per year, in 3 000 m altitude about 1.7 mSv per year. In the case of air travel, passengers receive an additional dose of cosmic radiation; for a flight Frankfurt - New York - Frankfurt about 0.1 mSv. →radiation exposure, cosmic

CP-1

Chicago Pile No. 1, first nuclear reactor (→Oklo). A group of scientists headed by Enrico Fermi succeeded with the first self-sustaining chain reaction on 2nd December 1942 in Chicago, IL, USA. Natural uranium was used as a fuel and graphite as moderator. Due to the low power of the reactor a special cooling was not necessary.

CP-1 during the critical test of the first self-sustaining chain reaction on 2nd Dec. 1942

Critical

A reactor is critical when due to nuclear fission as many neutrons are generated as are lost by absorption in the fuel, structure material and discharge. The critical condition is the normal operating condition of a reactor.

Critical experiment

Experiment to confirm calculations with regard to the →critical size and mass and other physical data influencing the reactor design.

Criticality

The condition of a nuclear reactor where a reaction initiates its own repetition.

Criticality accident

Accident resulting from the undesired creation of a critical arrangement. A criticality accident entails short-term high gamma and neutron radiation and energy release from nuclear fissions in the plant area concerned.

Criticality, prompt

The condition of a reactor in which the chain reaction is maintained only due to prompt neutrons, i.e. without the aid of delayed neutrons. →neutrons, prompt; →neutrons, delayed

Criticality safety

Safety against impermissible generation of critical or supercritical arrangements or conditions.

Critical mass

Smallest fissile material mass which under fixed conditions (type of fissile material, geometry, moderated/immoderate system, etc.) initiates a self-perpetuating chain reaction. The table contains the minimum critical mass for some nuclides under certain conditions.

isotope	smallest critical mass in spherical shape for aqueous solution, optimum moderation		smallest critical mass in spherical shape for metal (fast immoderate systems)	
	unreflected (kg)	water-reflected (kg)	unreflected (kg)	steel-reflected (kg)
U-233	1.080	0.568	15.8	6.1
U-235	1.420	0.784	46.7	16.8
Np-237	-	-	63.6	38.6
Pu-238	-	-	9.5	4.7
Pu-239	0.877	0.494	10.0	4.5
Pu-240	-	-	35.7	19.8
Pu-241	0.511	0.246	12.3	5.1
Am-241	-	-	57.6	33.8
Am-242m	0.042	0.020	8.8	3.0
Cm-243	0.280	0.127	8.4	3.1
Cm-244	-	-	26.6	13.2
Cm-245	0.116	0.054	9.1	3.5
Cm-247	4.060	2.180	6.9	2.8
Cf-249	0.129	0.060	5.9	2.4
Cf-251	0.048	0.025	5.5	2.3

Smallest critical masses for some fissile material under certain boundary conditions

Critical size

Minimum dimensions of a fuel arrangement which becomes →critical at a certain geometrical arrangement and material composition.

Crud

Term for precipitation in reprocessing processes generated from fission products, mainly zirconium together with radiolysis products of the solvent. These precipitations mainly gather at the phase interfaces between nuclear fuel dissolution and extracting agent and disturb the quantitative extraction.

Curie

Name for the former unit of activity. The activity of 1 curie, symbol: Ci, is equal to the decay of $3.7 \cdot 10^{10}$ (37 billion) atoms of a radionuclide per second. The activity unit curie was replaced by →Becquerel. 1 curie = $3.7 \cdot 10^{10}$ becquerels.

Cyclotron

Particle accelerator where charged particles repeatedly pass an electrical acceleration field while they move helically from their source in the centre of the machine to the outside. The particles are held in the helical level by a strong magnet. A cyclotron is not suitable to accelerate electrons. Due to the relativistic mass increase with growing speed the maximum energy achievable with a cyclotron is limited to about 400 MeV for protons.

D

DAtF

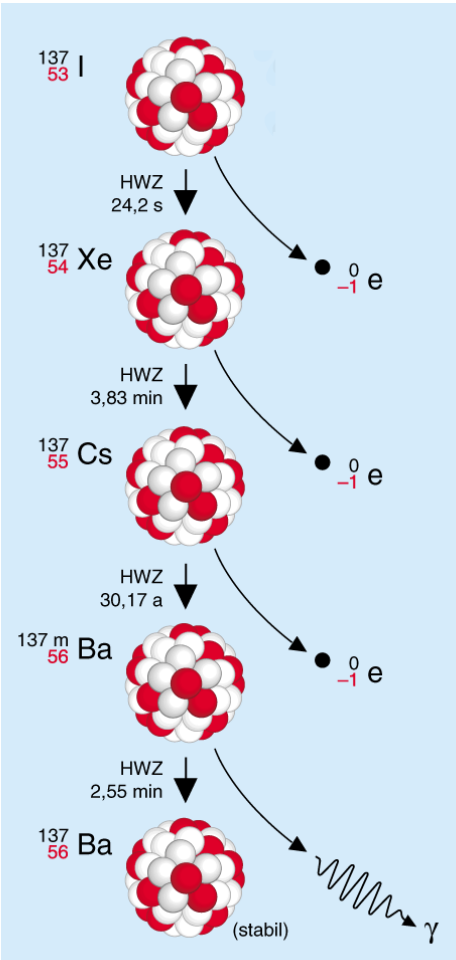
→Deutsches Atomforum e. V., i.e. German Atomic Forum, Robert-Koch-Platz 4, 10115 Berlin, Germany

Dating, radioactive

Method of measuring the age of an object by determining the ratio of various radionuclides to stable nuclides contained therein. It is therefore possible to determine e.g. from the ratio of carbon -14 to carbon-12 the age of bones, wood and other archaeological samples.

Daughter and grandchild nuclides

In a decay chain of radioactive substances, the daughter nuclide followed by the grandchild nuclide are the decay products of a parent nuclide. Example: iodine-137 (parent nuclide) decays via xenon-137 (daughter), caesium-137 (grandchild), barium-137m (great-grandchild) into the stable barium-137 (great-great-grandchild). →decay chain, natural



Parent / daughter / grandchild nuclides in the decay chain of iodine-137 to barium-137

DBE

Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH, Peine, i.e. German Company for the Construction and Operation of Repositories for Waste.

Decay

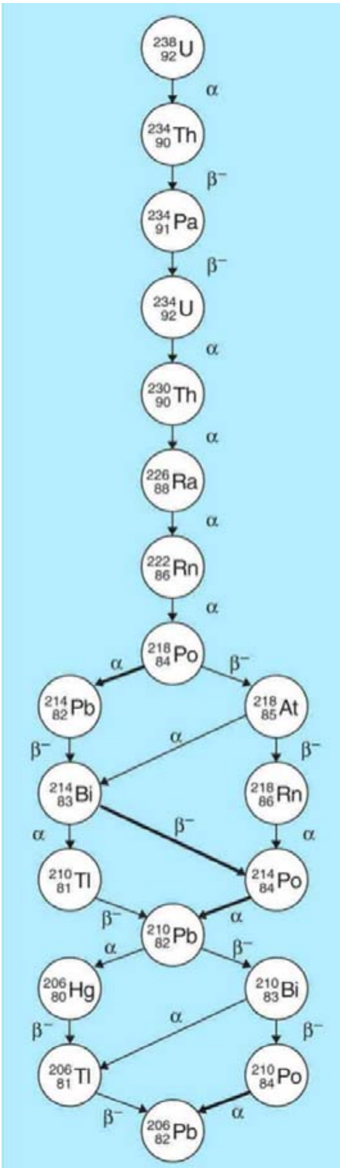
The spontaneous conversion of a nuclide into another nuclide or into another energy state of the same nuclide. Every decay process has a certain →half-life.

Decay basin

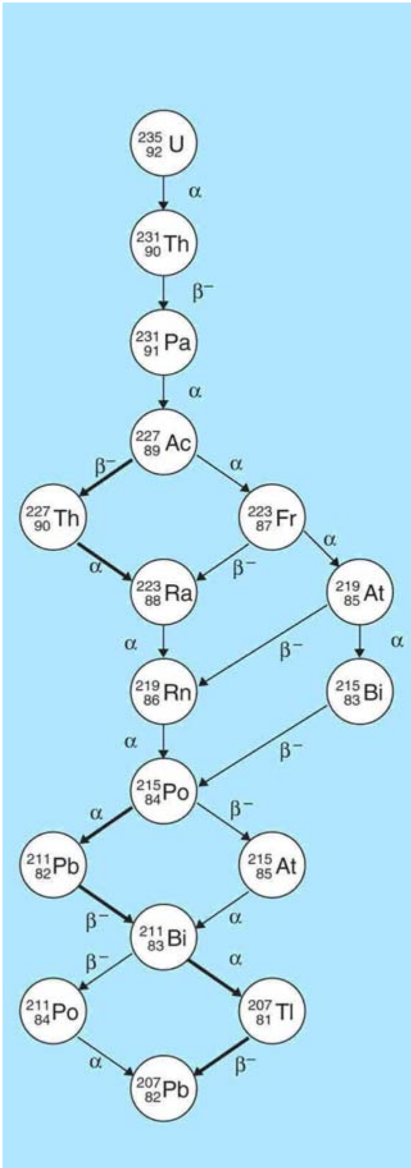
Basin filled with water to store fuel elements after use in the reactor until activity and heat generation have decreased to the desired value.

Decay chains, natural

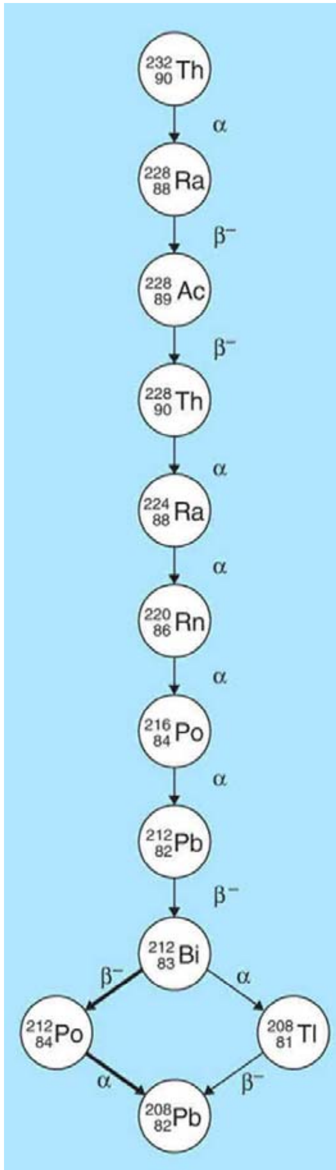
The nuclides generated during the decay of the very long-lived natural radionuclides U-238 (half-life 4.5 bn years), U-235 (half-life 0.7 bn years) and Th-232 (half-life 14 bn years) are in turn radioactive, and therefore decay again. Thus, the so-called decay chains are created which end only when a non-radioactive nuclide is formed. The uranium-radium decay chain starts from U-238 and ends via 18 intermediate states at the stable lead-206. Uranium-235 is at the beginning of the uranium-actinium decay chain leading via 15 radionuclides to lead-207. With ten intermediate states, the thorium decay chain starting with thorium-232 and ending at lead-208 is the shortest.



Uranium-Radium-chain



Uranium-Actinium chain



Thorium chain

Decay constant

The decay constant of radioactive decay is equal to the reciprocal value of the average →life time τ. Between the decay constant λ, the medium life time τ and the →half-life T the following relations exists:

$$\lambda = \tau^{-1} = T^{-1} \cdot \ln 2.$$

Decay time

The radioactive fission products in the fuel resulting from nuclear fission are the reason for the high initial radiation intensity and the heat generation of the fuel after its use in the reactor. Heat rate and activity of the irradiated fuel initially decrease rapidly due to the large share of short-lived radionuclides. The activity contained in irradiated fuel decreases to approx. 1/100 of the original value within one year of removal from the reactor.

Decommissioning of nuclear power plants

A prerequisite for the start of decommissioning work is that the nuclear fuel, coolant and the radioactive process waste are removed from the plant. Thus, the original activity inventory is reduced to a great extent to the activity contained in the activated and contaminated components. This residual activity is then mostly present in solid form and amounts after one year to less than one percent of the activity inventory of a plant in operation. Depending on the individual circumstances, three main decommissioning variants exist: safe enclosure, partial removal with safe enclosure and complete removal.

Decontamination

Elimination or reduction of radioactive →contamination using chemical or physical procedures, e.g. by rinsing or cleaning with chemicals. Air and water are decontaminated by filtering or evaporation and precipitation.

Decontamination factor

Ratio of activity prior to and after the decontamination of radioactively contaminated objects, waste water, air, etc.

Degree of enrichment

Enrichment factor minus 1

Delayed critical

The same as →critical. The term is used to emphasise that the →delayed neutrons are necessary to achieve the critical condition.

Demineralised water

Obtained by distillation or ion exchange processes for medical or technical purposes.

Depleted uranium

Uranium with a lower percentage of U-235 than the 0.7205% contained in natural uranium. It is produced during uranium isotope separation. The normal residual U-235 content in depleted uranium is 0.2%.

Depletion

Reduction of the relative frequency of a nuclide or several nuclides during a process.

Depth dose

→dose equivalent in 10 mm depth in the body at the point of application of the personal dosimeter, symbol: $H_p(10)$. →dose

Depth dose, relative

Term from radiology. Ratio of an absorbed dose in a certain depth within the body to an absorbed dose at a reference point of the body at the central ray. In the case of x-radiation or gamma radiation, the localization of the reference point depends on the radiation energy. For low energies it is at the surface, for high energies at the point of the highest value of the absorbed dose.

Design basis accident

Design basis accidents - pipe ruptures, component failure - must be controlled by the safety facilities in such a way that effects on the environment are kept below the specified planning values of the Radiation Protection Ordinance, i.e. the effective dose is less than 50 mSv. →MCA

Detection limit

Parameter determined on the basis of statistical procedures to evaluate the detection possibility for nuclear radiation measurements. The value of the detection limit allows a decision to be taken as to whether a contribution of the sample is contained in the registered pulses. →traceability limit for each measurement with given error probability.

Deterministic radiation effect

Effect of ionizing radiation leading to a functional loss of the irradiated organ or tissue, if sufficient cells are killed or prevented from reproducing or functioning due to radiation. The seriousness of this loss of organ function is directly proportional to the number of cells affected. Since the function of many organs and tissue is not impaired by a limited reduction in the number of functional cells, a threshold dose for deterministic radiation effects exists, which must be exceeded for an effect to occur. In the case of radiation doses above this threshold the degree of pathological severity increases rapidly. The deterministic effects of ionizing radiation include skin reddening (dose threshold 3 to 5 Gray), opacity of the eye lens (dose threshold 2 to 10 Gray) and permanent sterility (dose threshold 2.5 to 6 Gray).

Deuterium

Hydrogen isotope with a nucleus containing a neutron and a proton resulting in double the weight of the nucleus of normal hydrogen, which contains only one proton. It is therefore known as “heavy“ hydrogen. Deuterium occurs naturally. There is one deuterium atom per 6 500 “normal“ hydrogen atoms. →heavy water

Deuteron

Nucleus of the deuterium consisting of a proton and a neutron.

Deutsches Atomforum (German Atomic Forum)

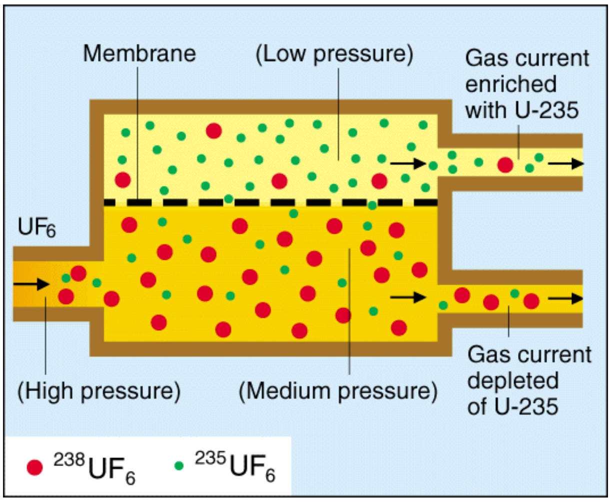
The Deutsches Atomforum e. V. is a private, non-profit association in which politics, the administration, economy and science are represented. The German Atomic Forum promotes the development and peaceful utilization of nuclear energy in Germany on the basis of voluntary co-operation. One of the main tasks of the German Atomic Forum is to inform the public about the peaceful utilization of nuclear energy. The office of the Deutsches Atomforum e.V., Robert-Koch-Platz 4. 10115 Berlin, answers questions and informs about the peaceful utilization of nuclear energy.

DIDO

Heavy-water-moderated and -cooled research reactor. The name is derived from D_2O, the chemical formula for heavy water.

Diffusion separation process

Isotope separation procedure using the different diffusion speeds of atoms or molecules of different weight through a porous wall for separation. The →degree of enrichment of the lighter component after flowing through the separation wall is determined by the root of the mass ratio of the particles. The diffusion separation process is employed on an industrial scale for uranium isotope separation where UF_6 is used as a process medium. The →separation factor per stage amounts to about 1.002. Connection in series in cascade form multiplies the separation effect. A uranium isotope separation plant according to this procedure is operated in Pierrelatte, north of Avignon.



Principle of a diffusion separation process

Direct cooling

Cooling of the turbine condenser in a power plant with non-recirculated river water. Direct cooling with fresh water is the cheapest cooling method regarding the required investment when sufficient river water is available. To avoid too high a thermal load of the river water, maximum values for the inlet temperature of the heated water (e.g. 30 °C), for the heating of the entire river water following mixing (25 °C or 28 °C) and the heating margin (3 °C) were fixed. As a result of the preload, a further thermal load is impossible for many rivers in Germany. Therefore, closed-circuit cooling is increasingly used.

Directional dose equivalent

The directional dose equivalent H'(0.07, Ω) at the point of interest in the actual radiation field is the dose equivalent which would be generated in the associated expanded radiation field at a depth of 0.07 mm on the radius of the →ICRU sphere which is oriented in the fixed direction Ω. An expanded radiation field is an idealized radiation field in which the particle flux density and the energy and direction distribution of the radiation show the same values at all points of a sufficient volume as the actual radiation field at the point of interest.

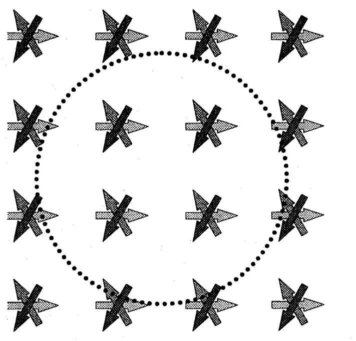


Diagram of an expanded radiation field

Direct radiation

Portion of radiation emitted by a radiation source which reaches the observed receiving point via the shortest distance, possibly weakened by existing shielding walls. The direct radiation is distinguished from scattered radiation which may reach the receiving point indirectly due to scattering on other media.

Disaster control plans

The authorities are obliged to carry out hazard defence planning and prepare a disaster control plan for nuclear power plants and for other large-scale facilities such as chemical factories, refineries, tank farms and also for natural disasters. Depending on the local circumstances, such a plan may provide evacuation measures for the population living in the immediate vicinity. The Conference of the Minister for the Interior and the Federal state committee for nuclear energy have therefore jointly passed „General recommendations for the disaster control in the vicinity of nuclear installations" in accordance with a proposal of the Commission on Radiological Protection.

Discussion date

Pursuant to the provisions in the nuclear licensing procedure ordinance, the licensing authority is required to fix a discussion date during the licensing for plants which generate, treat, process or fission nuclear fuel or reprocess irradiated fuel. The licensing authority is required to verbally discuss the objections raised against the project in good time with the applicant and those who have raised the objections. The discussion date serves to deal with the objections insofar as they are relevant for examination of the licensing prerequisites. Those who raised objections should be given the opportunity of explaining their objections. The discussion date is not public.

Dispersion calculations

Calculation method to determine the effects caused by the release of radioactivity with the exhaust air from nuclear power plants. These calculations take account of the meteorological conditions in the site region. The dispersion calculations are used to calculate the radiation exposure of human beings from the emission of radioactive substances with the exhaust air. →exhaust air path

Disposal precaution

A legal constraint (valid since 1974) for the disposal precaution of nuclear reactors regarding spent fuel elements according to the source-related principle by the operator of a nuclear power plant.

Dissolution device

Technical equipment in a reprocessing plant for the dissolution of nuclear fuel in acid. →PUREX process.

Dissolver

Container for the dissolution of nuclear fuel in acid during reprocessing.

District heating power plant

A steam power plant in which the steam is used not only for electricity generation, but also for heating purposes. The overall efficiency of the power plant is greater in this case than for power plants used only for electricity generation.

Diversity

Design principle for safety systems of nuclear plants. To increase fail-safeness, the safety devices are not only designed in multiple numbers - i.e. redundantly - but also on physically or technically different principles - diverse. →redundancy

Dodecane

n-dodecane, $C_{12}H_{26}$, melting point -9.6 °C, boiling point 216.3 °C, density 0.7493 g/cm³. Dodecane is a hydrocarbon (alkane), suitable as solvent to dilute →TBP in the extraction of U and Pu from irradiated nuclear fuel. →PUREX process

Dollar

Used in reactor physics to indicate →reactivity. Dollar is the unit of measure for the reactivity of a reactor related to the portion of delayed neutrons.

Doppler effect

Change in measured frequency of a wave structure due to the movement of the receiver or the wave source. The moved receiver cuts more or fewer waves per time unit, depending on whether the receiver moves towards the wave source or away from it. Analogously, the oscillations of the uranium atoms in a fuel element within a reactor lead to a Doppler effect due to the increasing operating temperature, since the fission cross-section depends on the relative velocity of the neutrons and uranium atoms. This Doppler effect may modify the reactivity of the reactor.

Dose

Measure of a radiation effect to be indicated more precisely. The absorbed dose indicates the total radiation energy absorbed by the irradiated matter in Gray (Gy). Central dose variables in radiation protection are „organ dose“ and „effective dose“. The term „body dose“ is used as a collective term for organ dose and effective dose. The latter two are protective variables in radiation protection, including risk assessment. They form a basis for the assessment of the probability of stochastic radiation effects for absorbed doses far below the thresholds for deterministic radiation damage. The unit of these dose values is Sievert, symbol: Sv.

The Radiation Protection Ordinance requires measurement of the personal dose for the determination of the body dose which cannot be measured directly. Personal dose is the dose equivalent measured in the measuring variables of depth dose and skin dose at an area of the body surface representative of radiation exposure. The depth dose $H_p(10)$ in this case is an estimated value for the effective dose for whole body exposure with penetrating radiation and the organ doses of deep organs and the skin dose $H_p(0,07)$ are an estimated value for the skin dose.

The dose variables used in radiation protection in more detail:

- Dose equivalent

  The dose equivalent is the product of the absorbed dose in ICRU →soft tissue and the →quality factor. In the case of several radiation types and radiation energies the total dose equivalent is the sum of its determined individual amounts. The unit of the dose equivalent is sievert.

- Effective dose

  The effective dose is the suitable variable to indicate a uniform dose value in case of different exposure of various body parts in order to evaluate the risk of late radiation injuries. The effective dose E is the sum of the average →organ doses H_T in the individual organs and tissues of the body due to external or internal radiation exposure multiplied by the tissue weighting factors w_T.

$$E = \sum_T w_T \ H_T \, .$$

Organ	Tissue weighting factor, w_T
Gonads	0.20
Colon	0.12
Bone marrow (red)	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05

Chest	0.05
Liver	0.05
Thyroid gland	0.05
Oesophagus	0.05
Skin	0.01
Bone surface	0.01
Pancreas, small intestine, uterus, brain, spleen, muscle, suprarenal gland, kidney, thymus gland	0.05

- Absorbed dose

The absorbed dose *D* is the quotient from the average energy transferred to the matter in a volume element by ionizing radiation and the mass of the matter in this volume element:

$$\mathbf{D} = \frac{\mathbf{d}\bar{\varepsilon}}{\mathbf{dm}}.$$

The unit of the absorbed dose is joule divided by kilogram ($J \cdot kg^{-1}$) and its special unit name is gray (Gy). The former unit name was rad (symbol: rd or rad).1 Gy = 100 rd; 1 rd = 1/100 Gy.

- Committed dose

The irradiation of tissue or organs by incorporated radionuclides is distributed over the incorporation period. This period depends upon the physical half-life and the biokinetic behaviour of the radionuclide. The committed dose is the time integral of the dose rate in a tissue or organ over time. The organ committed dose $H_T(\tau)$ for incorporation at time t_0 is the time integral of the organ dose rate in the tissue or organ T. If no integration period τ is indicated, a period of 50 years for adults and the period from the respective age to the age of 70 years for children are used as a basis:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)dt \, ;$$

- Skin dose

The skin dose $H_p(0.07)$ is the dose equivalent in 0.07 mm depth in the body at the application point of the personal dosimeter.

- Equivalent dose

The equivalent dose $H_{T,R}$ is the product of the organ absorbed dose $D_{T,R}$ averaged over the tissue/organ T generated by the radiation R and the radiation weighting factor w_R.

$$H_{T,R} = w_R \ D_{T,R}$$

If the radiation consists of types and energies with different w_R values, the individual values are added.

$$H_T = \sum_R w_R \ D_{T,R}$$

Radiation type and energy range	Radiation weighting factor w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons	
< 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20

> 2 MeV to 20 MeV	10
> 20 MeV	5
Protons, except for recoil protons, > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Radiation weighting factor

- Local dose

The local dose is the dose equivalent for soft tissue measured at a certain point. The local dose in the case of penetrating radiation is the ambient dose equivalent; the local dose for radiation with low penetration depth is the directional dose equivalent. The local dose in the case of penetrating radiation is an estimated value for the effective dose and the organ doses of deep organs for radiation with low penetration depth is an estimated value for the skin dose of a person at the place of measurement.

- Personal dose

The Radiation Protection Ordinance requires measurement of the personal dose for determination of the body dose. The personal dose is the dose equivalent measured in the measuring variables of depth dose and skin dose at a spot representative of radiation exposure at the body surface. The depth personal dose in the case of whole body exposure to penetrating radiation is an estimated value for the effective dose and the organ doses of deep organs and the skin dose an estimated value for the skin dose.

- Directional dose equivalent

The directional dose equivalent $H'(0.07, \Omega)$ at the point of interest in the actual radiation field is the dose equivalent which would be generated in the associated expanded radiation field at a depth of 0.07 mm on the radius of the →ICRU sphere which is oriented in the fixed direction Ω.

- Personal dose equivalent

The personal dose equivalent $H_p(10)$ is the dose equivalent at a body depth of 10 mm at the point of application of the personal dosimeter.

- Ambient dose equivalent

The ambient dose equivalent $H^*(10)$ at the point of interest in the actual radiation field is the dose equivalent which would be generated in the associated oriented and expanded radiation field at a depth of 10 mm on the radius of the ICRU sphere which is oriented opposite to the direction of incident radiation.

Dose build-up factor

Considers the influence of scattered radiation on the dose during shielding calculations.

Dose coefficient

Factor determining the radiation exposure of individual organs and the whole body by an incorporated radioactive substance. Dose coefficients depend on the radionuclide, the incorporation type (inhalation/ingestion), the chemical compound of the radionuclide and on the age of the person. In the Federal Gazette No. 160a and b dated 28th August 2001, the dose coefficients are listed in detail for members of the public and for occupationally exposed persons. They indicate the dose in 24 organs or tissues and the effective dose for inhaled or ingested activity of 1 becquerel.

Nuclide	**Organ**	**Dose coefficients in Sv/Bq**		
		< 1 year	**7 - 12 years**	**> 17 years**
H-3	effective dose	$6.4 \cdot 10^{-11}$	$2.3 \cdot 10^{-11}$	$1.8 \cdot 10^{-11}$
C-14	effective dose	$1.4 \cdot 10^{-9}$	$8.0 \cdot 10^{-10}$	$5.8 \cdot 10^{-10}$
Sr-90	bone surface effective dose	$2.3 \cdot 10^{-6}$ $2.3 \cdot 10^{-7}$	$4.1 \cdot 10^{-6}$ $6.0 \cdot 10^{-8}$	$4.1 \cdot 10^{-7}$ $2.8 \cdot 10^{-8}$
I-131	thyroid effective dose	$3.7 \cdot 10^{-6}$ $1.8 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$ $5.2 \cdot 10^{-8}$	$4.3 \cdot 10^{-7}$ $2.2 \cdot 10^{-8}$
Cs-137	effective dose	$2.1 \cdot 10^{-8}$	$1.0 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$

Nuclide	Organ	Dose coefficients in Sv/Bq		
		< 1 year	7 - 12 years	> 17 years
Ra-226	bone surface effective dose	$1.6 \cdot 10^{-4}$ $4.7 \cdot 10^{-6}$	$3.9 \cdot 10^{-5}$ $8.0 \cdot 10^{-7}$	$1.2 \cdot 10^{-5}$ $2.8 \cdot 10^{-7}$
Pu-239	bone surface effective dose	$7.4 \cdot 10^{-5}$ $4.2 \cdot 10^{-6}$	$6.8 \cdot 10^{-6}$ $2.7 \cdot 10^{-7}$	$8.2 \cdot 10^{-6}$ $2.5 \cdot 10^{-7}$

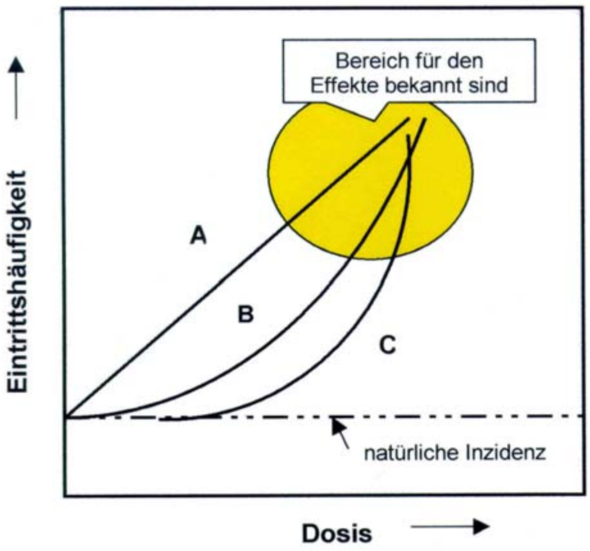
Examples of dose coefficients for members of the public for the calculation of the organ dose or the effective dose due to ingestion of radionuclides

Dose effect curve

Term from radiation biology denoting the relationship between the percentage occurrence of an examined effect as a function of the irradiated dose.

Dose-effect relation

Relation between the dose of an organ, part of the body or the whole body and the resulting biological radiation effect. Various expolation possibilities derived from knowledge gained with high doses are conceivable for a few millisieverts - the area of interest for radiation protection purposes. The International Commission on Radiological Protection assumes for the purposes of radiation protection a linear relation between the level of the effective dose and the frequency of late radiation damage.



Dose-effect relationship;

Course of extrapolation possibilities:

A: linear
B: linear-quadratic
C: quadratic with threshold value

Dose equivalent

According to ICRU Report 51 the dose equivalent, *H*, is the product of *Q* and *D* at a point in tissue, where *D* is the →absorbed dose and *Q* is the quality factor at that point, thus

$$H = Q\,D.$$

The unit is J kg-1, the special name for the unit of dose equivalent is sievert (Sv). The quantity dose equivalent is defined for routine radiation-protection applications. It should not be used in the numerical assessment of high-level exposure, for example in radiation accidents.

In 1991 the International Commission on Radiological Protection introduced for dose limitation proposes a quantity called organ dose equivalent, based on the radiation weighting factor w_R and $D_{T,R}$ the mean absorbed dose in a tissue or organ. Accordingly, the organ equivalent dose $H_{T,R}$ in a tissue or organ *T* by the radiation type *R* is:

$$H_{T,R} = w_R \cdot D_{T,R}.$$

In a mixed radiation field the following equation applies for the overall organ equivalent dose H_T in a tissue or organ *T*:

$$H_T = \sum_R w_R \cdot D_{T,R} .$$

The unit is joule/kg (J/kg). The special name for the unit of the organ dose is sievert, symbol: Sv. Occasionally the former unit name rem is used. 1 sievert is equal to 100 rem. The quantity organ dose equivalent is only used in radiation protection. These quantity offer a basis for the estimation of →stochastic radiation effects for radiation doses far below the threshold values for →deterministic radiation effects.

Dose equivalent rate

Quotient from the dose equivalent in a period of time and this time, e.g. millisievert/hour (mSv/h).

Dose limit value

Dose value of an ionizing radiation fixed by the legislator as a maximum to which a person may be exposed based on recommendations from scientific committees. Different dose limit values are fixed for different groups of persons. When handling radioactive substances and ionizing radiation the principle that any unnecessary radiation exposure is to be avoided must be observed and if unavoidable it is to be kept as low as possible, even when within the legal limit values. The German Radiation Protection Ordinance and the X-Ray Ordinance fixes the limit values for occupationally exposed persons as listed in the table. Lower values apply for occupationally exposed pregnant women and apprentices.

Tissue or organ	Limit
Effective dose	20 mSv/year
Organ dose	
Bone marrow (red), gonads, uterus	50mSv/year
Adrenals, bladder, brain, breast, lens of the eye, small intestine, upper large intestine, kidney, liver, lung, muscle, oesophagus, pancreas, spleen, stomach, thymus	150 mSv/year
Bone surface, thyroid	300 mSv/year
Ankles, feet, forearms, hands, skin	500 mSv/year

Dose limits for occupationally exposed persons

The effective dose for members of the public must not exceed 1 mSv/year. The limit for the lens of the eye is 15 mSv/year and for the skin 50 mSv/year. The party responsible for radiation protection is required to plan the technical rating and operation of nuclear plants such that the following limit values are not exceeded by radioactive emissions with exhaust air or waste water:

Effective dose and dose for gonads, uterus, red bone marrow	0.3 mSv/year
Dose for adrenals, bladder, brain, breast, small intestine, upper large intestine, kidney, liver, lung, muscle, oesophagus, pancreas, spleen, stomach, thyroid, thymus	0.9 mSv/year
Dose for bone surface, skin	1.8 mSv/year

These dose limits shall be observed at the most unfavorable point of effect, taking account of all relevant load paths, the dietary and lifestyle habits of the reference person in addition to any possible prior contamination by other plants and facilities.

Dose rate

The dose rate is the quotient of dose and time; e.g. the dose rate in radiation protection is often indicated in microsievert per hour (µSv/h).

Dosimeter

An instrument to measure the personal or local dose (→ionization chamber, →film dosimeter, →phosphate glass dosimeter, →thermoluminescence dosimeter).

Dosimetry

Measuring procedure to determine the dose equivalent generated by ionizing radiation in matter.

Doubling time

The time during which the fissile material input of a breeding reactor doubles. Depending on the breeding reactor concept, doubling times of 8 to 20 years result.

Dry cooling tower

Cooling tower for the closed-circuit cooling of water with no direct contact between the water to be cooled and the coolant air. The heated water - similarly to a motor radiator - is cooled by air and returned to the condenser.

Dry storage

Storage of spent fuel elements without using water as a coolant.

DTPA

Diethylenetriamine pentaacetate; chelators. Chelators are organic compounds capable of integrating metal ions in the organic molecule in such a way that the metal ion loses its chemical properties essential for its biological behaviour and can therefore be excreted more rapidly from the body. Thus, effective decorporation agents in the form of Ca-DTPA and Zn-DTPA - in particular for plutonium - are available.

E

ECCS

→Emergency Core Cooling System.

Ecology

Science of the relations between the organisms and their environment. In particular, it investigates the adaptation of living things to their living conditions.

Ecosystem

Spatial fabric of interaction composed of living creatures and environmental conditions, which is capable of self-regulation.

Efficiency

Ratio of machine output and input. The efficiency is related to a certain operating point, e.g. full-load operation.

Electromagnetic isotope separation

Separation of different isotopes by means of electrical and magnetic fields.

Electromagnetic radiation

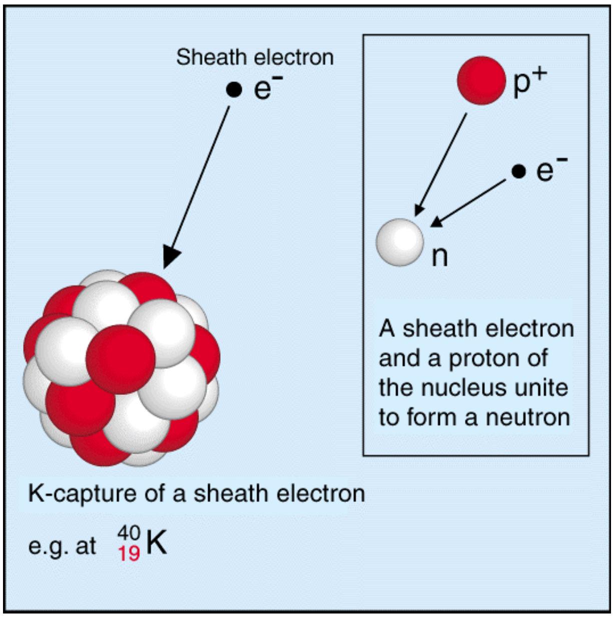
Radiation from synchro systems and magnetic waves travelling at the speed of light. Examples: light, radio waves, →x-rays, →gamma rays. Electronic radiation also propagates in a vacuum.

Electron

Elementary particle with a negative electrical elementary charge and a rest mass of $9.1094 \cdot 10^{-31}$ kg (corresponding to a rest-energy of 511 keV). This is 1/1836 of the proton mass. Electrons surround the positively charged nucleus of an atom and determine the chemical behaviour of the atom. Occasionally, the negative electron is also called negatron and the electron used as a general term for negatron and →positron.

Electron capture

Disintegration type of some radionuclides, e.g. K-40, Mn-54, Fe-55. The nucleus of an atom captures an electron of the atomic shell, whereby a proton in the nucleus converts into a neutron. The formed nuclide has an atomic number which is smaller by one unit; the mass number remains the same. Example: K-40 + e^- → Ar-40.



Electron capture; capture of an electron from the nuclear shell of the electron sheath during the disintegration of potassium-40 into argon-40

Electron equilibrium

Dosimetry term. Electron equilibrium is present when, due to ionization events within and outside this volume element, the same number of electrons with the same energy distribution enter and exit this volume element.

Electron volt

Commonly used unit of energy in atomic and nuclear physics. An electron volt is the kinetic energy gained by an electron or other simply charged particles when passing through a voltage difference of 1 Volt in vacuum. 1 eV is equal to the energy of $1.602 \cdot 10^{-19}$ J. Deviated greater units:

Kiloelectron volt (keV) = 1 000 eV,

Megaelectron volt (MeV) = 1 000 000 eV,
Gigaelectron volt (GeV) = 1 000 000 000 eV.

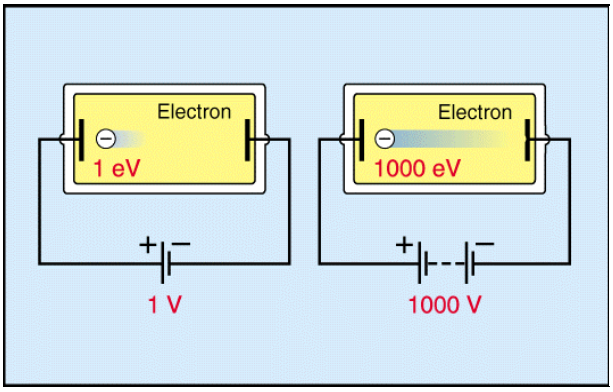


Illustration of the electron volt energy unit

Element

Chemical base material which cannot be chemically converted into simpler substances. Examples: oxygen, aluminium, iron, mercury, lead, uranium. At present 118 different elements are known, some of which do not occur in nature and were artificially generated: technetium, promethium and all elements with a higher atomic number than that of uranium.

Element, artificial

Element not or no longer occurring on earth, but artificially generated by nuclear reaction. The artificial elements include the elements technetium (atomic number Z = 43), promethium (Z = 61) and the transuraniums (Z > 92). A total of 118 elements are therefore known today. In the 70's, it could be verified that very low traces of plutonium occur in nature resulting from natural nuclear fissions (about 1 plutonium atom per 10^{12} uranium atoms).

element name	symbol	atomic number	element name	symbol	atomic number
Technetium	Tc	43	Dubnium	Db	105
Promethium	Pm	61	Seaborgium	Sb	106
Neptunium	Np	93	Bohrium	Bh	107
Plutonium	Pu	94	Hassium	Hs	108
Americium	Am	95	Meitnerium	Mt	109
Curium	Cm	96	Darmstadtium	Ds	110
Berkelium	Bk	97	Roentgenium	Rg	111
Californium	Cf	98	Copernicium	Cn	112
Einsteinium	Es	99	still without name		113
Fermium	Fm	100	Flerovium	Fl	114
Mendelevium	Md	101	still without name		115
Nobelium	No	102	Livermorium	Lv	116
Lawrencium	Lw	103	still without name		117
Rutherfordium	Rf	104	still without name		118

List of artificial elements

Elementary charge

Smallest electric charge unit ($1.6021 \cdot 10^{-19}$ Coulomb). The electric charge occurs only in integral multiples of this unit. An electron has a negative, a proton a positive elementary charge.

Elementary particles

Elementary particles refer to particles that cannot be easily recognized as a compound - in contrast to the nuclei of atoms. Within certain limits determined by the conservation rates, elementary particles can be converted.

Elementary particles

Elementary particles refer to particles that cannot be easily recognized as a compound - in contrast to the nuclei of atoms. Within certain limits determined by the conservation rates, elementary particles can be converted.

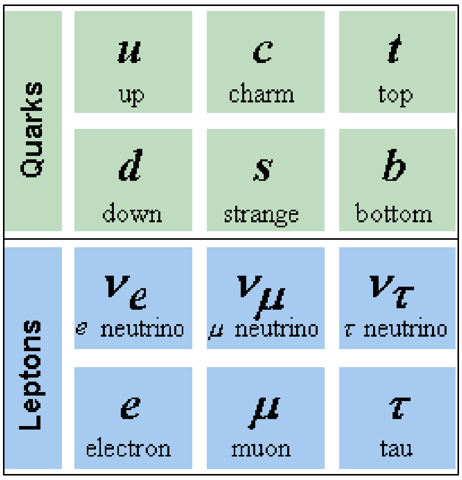
Particle	Rest mass MeV	Average lifetime s	Most frequent type of decay	%
Photon				
γ	0 (< $1 \cdot 10^{-24}$)	stable	stable	
Leptons				
ν_e	0 (< $2 \cdot 10^{-6}$)	stable	stable	
ν_μ	0 (< 0.17)	stable	stable	
ν_τ	0 (< 15.5)	stable	stable	
e	0.510998928	stable (> $4.6 \cdot 10^{26}$ a)	stable	
μ	105.6583715	$2.19703 \cdot 10^{-6}$	$e^- \ \bar{\nu}_e \ \nu_\mu$	98.6
				1.4

Particle	Rest mass MeV	Average lifetime s	Most frequent type of decay	%
τ	1777.03	$2.906 \cdot 10^{-13}$	$e^- \bar{\nu}_e \nu_\mu \gamma$ $e^- \bar{\nu}_e \nu_\tau$ $\mu^- \bar{\nu}_\mu \nu_\tau$	 17.83 17.41
Mesons				
π°	134.9766	$8.4 \cdot 10^{-17}$	$\gamma\gamma$ $\gamma e^+ e^-$	98.8 1.2
$\pi^\pm$	139.57018	$2.6033 \cdot 10^{-8}$	(for π^+) $\mu^+ \nu_\mu$ $e^+ \nu_e$ $\mu^+ \nu_\mu \gamma$	 99.98 0.01 0.01
η	547.853		$\gamma\gamma$ $\pi^\circ \pi^\circ \pi^\circ$ $\pi^+ \pi^- \pi^\circ$ $\pi^+ \pi^- \gamma$	389.3 312.2 23.0 4.9
$K^\pm$	493.677	$1.2380 \cdot 10^{-8}$	(for K^+) $\mu^+ \nu_\mu$ $\pi^+ \pi^\circ$ $\pi^+ \pi^+ \pi^-$ $e^+ \nu_e \pi^\circ$ $\mu^+ \nu_\mu \pi^\circ$ $\pi^+ \pi^\circ \pi^\circ$	 63.55 20.66 5.07 4.82 3.18 1.76
K° (50 % K_S^0, 50 % K_L^0)	497.614	K_s $8.957 \cdot 10^{-11}$ K_L $5.17 \cdot 10^{-8}$	(for K_S) $\pi^+ \pi^-$ $\pi^\circ \pi^\circ$ (for K_L) $\pi^\pm e^\mp \nu_e$ $\pi^\pm \mu^\mp \nu_\mu$ $\pi^\circ \pi^\circ \pi^\circ$ $\pi^+ \pi^- \pi^\circ$ $\pi^\pm e^\mp \nu_e \gamma$	 69.20 30.69 40.55 27.04 19.52 12.54 0.38
D°	1864.86	$0.4101 \cdot 10^{-12}$		
$D^\pm$	1869.62	$1.040 \cdot 10^{-12}$		
$D_s^\pm$	1968.49	$0.500 \cdot 10^{-12}$		
$B^\pm$	5279.25	$1.641 \cdot 10^{-12}$		
B°	5279.58	$1.519 \cdot 10^{-12}$		
B_s^o	5366.77	$1.497 \cdot 10^{-12}$		
$B_c^\pm$	6277	$0.453 \cdot 10^{-12}$		
Baryons				
p	938.272046	stable (> 2.1 10^{29} a)	stable	
n	939.565379	880.1	$p e^- \bar{\nu}_e$	100

Particle	Rest mass MeV	Average lifetime s	Most frequent type of decay	%
$\Lambda°$	1115.683	$2.632 \cdot 10^{-10}$	$p\,\pi^-$ $n\,\pi°$	63.9 35.8
Σ^+	1189.37	$8.018 \cdot 10^{-11}$	$p\,\pi°$ $n\,\pi^+$	51.6 48.3
$\Sigma°$	1192.642	$7.4 \cdot 10^{-20}$	$\Lambda°\,\gamma$	100
Σ^-	1197.449	$1.479 \cdot 10^{-10}$	$n\,\pi^-$	99.9
$\Xi°$	1314.86	$2.90 \cdot 10^{-10}$	$\Lambda°\,\pi°$	99.5
Ξ^-	1321.71	$1.639 \cdot 10^{-10}$	$\Lambda°\,\pi^-$	99.9
Ω^-	1672.45	$8.21 \cdot 10^{-11}$	$\Lambda°\,K^-$ $\Xi°\,\pi^-$ $\Xi^-\,\pi°$	67.8 23.6 8.6

Properties of some elementary particles, Particle Data Group, 2012

The multitude of such „elementary particles“ – in addition to those listed in the table, a further 200 were found - led to the „invention“ and eventually to the discovery of the „quarks“ and subsequently to today's „standard model“ of elementary particles. This standard model consists of twelve parts - see figure - and the same number of antiparticles. Thus, the proton consists of two „up-quarks“ and one „down-quark“, the neutron of one „up“ and two „downs“, where the up-quark has a charge of -2/3 and the down-quark +1/3 electric elementary charges to meet the electric charge conditions.



Standard model of elementary particles

Emergency core cooling system

Reactor cooling system for safe removal of residual heat in the case of an interruption of the heat transfer between reactor and heat sink. The emergency cooling systems are designed so that even in the case of reactor coolant loss - e.g. when both ends of a live-steam pipe are broken - the reactor is cooled and the decay heat can be removed over weeks. By means of redundant design a very high degree of functional safety is achieved. Thus, emergency cooling is guaranteed even if a subsystem fails.

Emission

The discharge (e.g. solid, liquid or gaseous substances, sound) originating from a source, e.g. industrial plant, household, traffic.

Emission height

The height of an emission source above ground. It is a parameter in dispersion calculation. Due to the thermal lift in the air, the effective emission height may be above the stack height (thermal amplified region).

Enclosed radioactive substances

Radioactive substances continuously enclosed by a tight, firm, inactive shell or which are continuously embedded in firm inactive substances so that in the case of normal operational load, the release of radioactive substances is safely avoided; a dimension must at least amount to 0.2 cm.

Energy

Ability to do work or diffuse heat. The unit of energy is the joule (J).

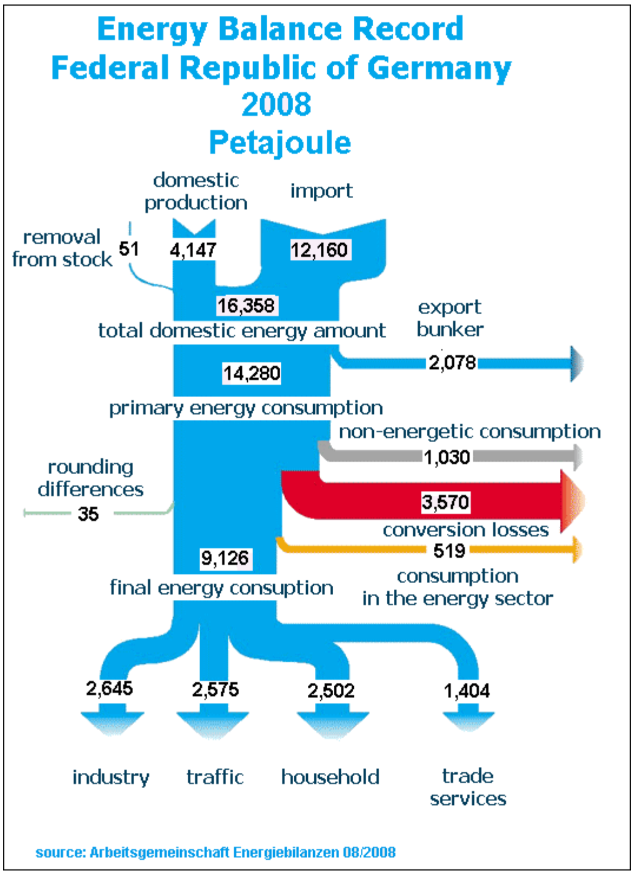
Energy balance record

An energy balance record is a survey of the sourcing, transformation and use of all forms of energy within a specified economic area (borough, company, country, state) during a defined period (e. g. month, year).

Energy balance records show the quantitative flow of the energy from different sources, starting from its origin and continuing with its transformation and consumption by the user, in the form of a balance sheet. They are a major basis for decisions on energy policy and the energy industry as well a for predictions on the development of the energy demand. The energy balance sheets provide relevant information about

- the extent and structure of energy consumption,
- changes in energy consumption,
- the contributions of the different domestic and imported enrgy sources,
- the transformation of energy carriers and
- the distribution of the energy consumed over the different consumption sectors.

For Germany, energy balance records are compiled e. g. by "Arbeitsgemeinschaft Energiebilanzen", an organisation supported by energy industry associations and economic research institutes.



Simplified energy flow diagram for Germany for the year 2008

Energy carrier

Oil, coal, gas, uranium, but also dammed or flowing water, sunlight and wind are energy carriers. They contain energy in different forms, which can be converted into a usable energy form if required.

Energy conversion

Conversion of one energy form into another - e.g. mechanical into electric energy in the generator - or of one energy carrier into another - e.g. coal into coke and gas. The starting energy can never be completely converted into the target energy. The difference is called conversion loss and mostly occurs as heat.

Energy requirement

Calculations in the United Nations show that the world population will increase to about 10 billion people by 2050. Parallel to the population growth, the global energy requirement will rise considerable despite all further efforts concerning the rational use of energy. According to calculations by the World Energy Council (WEC), the world-wide primary energy consumption of currently about 12 billion t →coal equivalent per year will grow to a level of between 16 and 24 billion t coal equivalent per year depending on the economic, social and political developments by the year 2020. This growth will mainly be based on fossil energy carriers which presently cover hardly 90% of the requirement. Hydrodynamic power and nuclear power cover at present about five percent each of the remaining 10 percent.

Energy reserves

Reserves of energy carriers are clearly identifiable stock which can be technically and economically mined under today's conditions or those to be expected in future. Resources are stock exceeding the reserves. They have been verified or are probable, but cannot be obtained at present for technical and/or economical reasons. The resources also include deposits that are not yet verified, but geologically possible. Thus, it is assumed that oil is bound in oil sands and oil shales, the mining of which is however uneconomical in view of the present price structure. The guaranteed and economically minable energy reserves as of 2011 of natural gas, mineral oil, uranium and coal world-wide amount to the following quantities:

Natural gas	245 billion t coal equivalent,
Mineral oil	239 billion t coal equivalent,
Uranium	36 billion t coal equivalent,
Coal	748 billion t coal equivalent.

The world total annual energy consumptions amounts to 17 billion coal equivalent.

Energy units

The unit of mass for energy is joule, symbol: J. The former unit kilocalorie (kcal) was replaced by joule on adoption of the international system of units in Germany from 1st Jan. 1978. In nuclear physics the energy values are mainly indicated in →electron volt (eV). $1 \text{ eV} = 1.602 \cdot 10^{-19}$ J. The indication of energy values in kilowatt hours (kWh) is widely used: $1 \text{ kWh} = 3.6 \cdot 10^{6}$ J. Related to the energy content of coal also the coal equivalent is usual in energy supply: 1 tonne coal equivalent is equal to 1 tonne coal with a calorific value of 29.3 billion joule = 7 million kcal.

Engineered storage

English designation for a certain type of storage, e.g. for waste. The material to be stored is still accessible, further treatment or transport to a repository can be effected later.

Enriched uranium

Uranium in which the percentage of the fissionable isotope U-235 is increased beyond the content of 0.7205% in naturally occurring uranium. Various enrichment methods are possible: →diffusion separation procedure, →gas centrifuge procedure, →nozzle process.

Enrichment

Process by which the share of a certain →isotope in an element is increased.

Enrichment chains

Radioactive isotopes of an element behave chemically in the same way as its non-radioactive isotopes. They can thus deplete or enrich in plants, animals and in the human body. Such an enrichment chain exists e.g. in the case of iodine. Iodine is finally enriched in the human thyroid gland via air - grass - cow - milk. These enrichment processes are known and can be calculated. To avoid higher radiation exposure in the corresponding organs due to the enrichment chains, the admissible release values for such radioactive substances are fixed correspondingly low. The →dose limit values prescribed by laws and regulations must not be exceeded - not even by enrichment effects.

Enrichment factor

Ratio of the relative frequency of a certain isotope in an isotope mixture to the relative frequency of this isotope in the natural isotope mixture.

Enrichment method

→isotope separation

ENS

European Nuclear Society

Environmental load

Disturbance in ecological systems caused by humans, resulting in deviations from normal behaviour.

Environmental monitoring

Monitoring of the vicinity of a plant for harmful substances, noise and other aspects considering defined measuring points, e.g. plant border, settlement zones and similar. Monitoring can also be performed by automatic recording and warning measuring stations. Operators of nuclear facilities are obliged to monitor the environment.

EPR

The EPR™ reactor is a new Generation III+ Pressurised Water Reactor (PWR) designed and manufactured by AREVA with a power generation capacity of up to 1660 MWe, which places it among the most powerful reactors in the world. A direct descendant of the last models manufactured by AREVA in France (N4) and Siemens in Germany (Konvoi), the EPR™ pressurized water reactor is based on tried-and-tested technologies and principles. This reactor design was previously called European Pressurized Reactor or Evolutionary Power Reactor, but now it is simply named EPR, a trademark by AREVA.
From a safety point of view, the EPR™ reactor ensures a very high level thanks to diversified, redundant active and passive safety systems to drastically reduce of the probability of severe accidents compared to existing Generation II reactors as well as to ensure that there will be no impact on the surrounding area, whatever the situation. In particular, it is highly resistant to external incidents (large commercial airplane crash, etc.) and features multiple protected power sources and water reserves. Through improved thermal efficiency the EPR™ reactor achieves a significant reduction in uranium consumption and production of long-lived radioactive waste
As of January 2013, four units are under construction - in Finland (Olkiluoto), in France (Flamanville) and in China (two units in Taishan).

Equilibrium, radioactive

Radioactive equilibrium denotes a condition which occurs during a radioactive decay chain for which the half-life of the starting nuclide is greater than the half-lives of the decay products when a period has passed which is about ten times as long in relation to the longest half-life of the decay products. The activity ratios of the members of the decay chain are time-constant in this case.

Equipment availability factor

Ratio of available time (operating and standby time) of a power plant to the calendar period. The equipment availability characterizes the reliability of a plant without considering rating deficiency during the operating time. →energy availability factor

ERAM

Endlager für **r**adioaktive **A**bfälle **M**orsleben, i.e. repository for radioactive waste Morsleben

Euratom basic safety standards

Guideline of the Council of the European Union dated 13th May 1996 to stipulate the basic safety standards for the protection of labour and the population against the hazards of ionizing radiation; published in the Federal Gazette of the EC No. L 159 dated 29th June 1996. The basic standards of 13th May 1996 are geared to the new scientific findings in radiological protection contained in the →ICRP Publication 60. The member states of the EU are obliged to enact the required national legal and administrative regulations to implement the Euratom basic standard by 13th May 2000.
On 29 Oct 2011 the European Commission issued a "Proposal for a Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation; Draft presented under Article 31 Euratom Treaty for the opinion of the European Economic and Social Committee" http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0593:FIN:EN:PDF to be adopted by the Council of Ministers of the European Union

Eurochemic

Reprocessing plant near Mol/Belgium, large-scale experimental plant established by the OECD states in 1957. From 1966 to 1974, a total of 182 t of natural and low enriched uranium and 30.6 t of fuel elements of high-enriched uranium were reprocessed. A commemorative stamp was issued by Belgian Post in 1966.

Commemorative stamp, 1966, EUROCHEMIC MOL

European Pressurized Water Reactor

→EPR

eV

Symbol for →electron volt.

EVA

Einwirkungen **v**on **a**ußen, i.e. external impacts. Within the scope of the nuclear licensing procedure for nuclear power plants and nuclear facilities, proof must be provided that the facility withstands specified service conditions such as earthquakes, aircraft crash and blast waves.

Evacuation plans

Disaster control plans for the environment of nuclear power plants and large nuclear facilities also comprise plans for the evacuation of the population in the case of catastrophic accidents in the plant pursuant to the general recommendations for disaster control in the environment of nuclear facilities. However, the measures for evacuation constitute only the extreme borderline case in a large number of protective measures provided in disaster control plans.

Examination threshold

Value of the body dose or activity intake if, when exceeded, examinations on the effects of radiation pro-tecttion measures are required. The value depends on the respective operation mode or type of application. →intervention threshold

Excess reactivity

Higher reactivity value than required to achieve criticality of a reactor. Provision is made for excess reactivity in the loading of a reactor with fuel elements to balance →burnup and the accumulation of →fission product poisons during operation. The excess reactivity existing in a freshly loaded reactor is balanced by the position of shim and control rods or by adding boron to the reactor coolant.

Excitation energy for nuclear fission

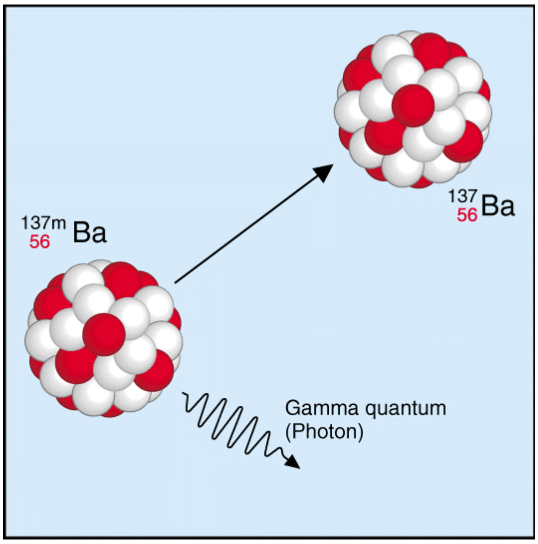
The fission of a nucleus basically requires the supply of a minimum energy. If a neutron is attached to a nucleus an energy is released consisting of the kinetic energy of the neutron and the binding energy of this neutron to the nucleus. If this energy is greater than the excitation energy for a fission of this nucleus, the nucleus may fission. For U-235 the excitation energy for fission amounts to 5.7 MeV, the binding energy of the attached neutron is 6.5 MeV, so that even neutrons with very low kinetic energies (e.g. thermal neutrons with a kinetic energy of only 0.025 eV) may trigger the fission. The ratios of excitation energy and binding energy are similar for the nuclei of U-233, Pu-239 and Pu-241. For U-238 and Th-232, on the other hand, the excitation energy required for fission is 6.5 MeV and thus much higher than the binding energy of the attached neutron of 4.8 MeV, so that fission of the nucleus is possible only if the neutron has a kinetic energy of at least 1.7 MeV. Spontaneous fission is also possible in the case of some very heavy nuclei. →fission, spontaneous

Nucleus	Excitation energy for fission, MeV	Binding energy of the last neutron, MeV
Th-232	6.5	4.8
U-233	6.2	6.8
U-235	5.7	6.5
U-238	6.5	4.8
Pu-239	5.8	6.5
Pu-240	6.2	5.2
Pu-241	5.6	6.3

Excitation energy for fission

Excited state

State of an atom or a nucleus with a higher energy than that of its normal energetic state. The excessive energy is generally emitted as photons (gamma quantum). Example: Ba-137m changes into the normal state of Ba-137 emitting a gamma quantum with the energy of 662 keV.



Emission of a gamma quantum (gamma radiation, γ-radiation) from an excited atomic nucleus

Exclusion area

Area of the →controlled area in which the local dose rate may be higher than 3 mSv per hour.

Excursion

Fast power increase in a reactor due to a high supercriticality. Excursions are generally quickly suppressed by the negative →temperature coefficient of reactivity or by →control rods.

Exhaust air path

Assumption models to calculate the →radiation exposure through radioactive waste disposal in the exhaust air of a nuclear plant. The result of such a dispersion calculation supplies local concentration values for radionuclides. The radiation generated during the decay of these radionuclides may in principle lead to a radiation exposure for human beings via the following paths:

- External irradiation through beta radiation within the effluent flume,
- External irradiation through gamma radiation within the effluent flume,
- External irradiation through gamma radiation from radioactive substances deposited on the ground,
- Internal irradiation through inhalation of radioactive substances in the air,
- Internal irradiation through ingestion of radioactive substances with food via
    - air – plant,
    - air – forage plant – cow – milk,
    - air – forage plant – animal – meat,
    - mother's milk.

Models and calculation assumptions for radiation exposure via the exhaust air path are included in the administrative instruction "Determination of radiation exposure through radioactive waste disposal from nuclear plants or facilities".

Experimental reactor

Nuclear reactor specially designed for the testing of material and reactor components under neutron and gamma fluxes and temperature conditions of a normal power plant reactor operation.

Experimentation channel

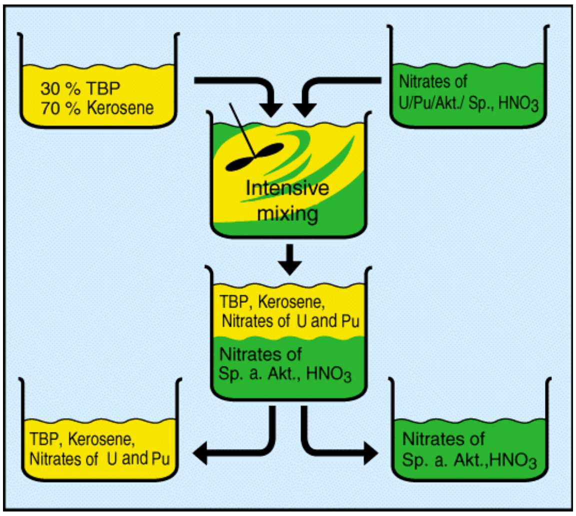
Opening in the shield of an experimental reactor through which radiation may exit for experiments outside the reactor.

Exposure path

Path of radioactive substances, ranging from discharge from a nuclear plant or facility via a propagation or transport process to radiation exposure of human beings.

Extraction

Process principle for the separation of fission products from the fuels uranium and plutonium according to the PUREX process. The aqueous solution of fuel and fission products is placed in homogenous contact with an organic solution that cannot be mixed. The organic solvent in the →PUREX process consists of a mixture of tributylphosphate (TBP) and kerosene. In extraction according to the PUREX process, advantage is taken of the fact that the substances uranyl nitrate and plutonium nitrate included in the aqueous solution are readily soluble in the mixture of TBP and kerosene whereas the fission products in this organic phase are practically insoluble. The separation is effected in extractors, i.e. apparatuses in which the two phases are collided in countercurrents, intensively mixed and separated again in settling chambers.



Extraction principle

Extractor

Extraction device, e.g. mixer-settler, pulse column in which multi-stage extraction is carried out.

F

Fail safe

A system designed in a way that if a subsystem fails, the entire system changes to a safe condition.

Fallout

Radioactive material which falls back to the earth after the release into the atmosphere (e.g. by nuclear weapon tests, accidents). The fallout occurs in two forms: the close fallout consists of heavy particles which fall to the ground within some days near the place of release and in an area which, depending on the weather conditions, may reach up to several hundred kilometres in the wind direction. The world-wide fallout consists of lighter particles reaching higher atmospheric layers and distributed over a wide part of the earth because of atmospheric currents. These particles eventually come down to the ground, mainly with precipitations, over periods of between months and several years. In the 60s, the radiation exposure in Germany caused by the fallout of nuclear weapon tests amounted to 0.1 to 0.4 mSv per year. At present it is less than 0.01 mSv per year; the overall dose in the period from 1960 to 2010 is estimated to be 2 mSv. The radiation exposure by the fallout due to the reactor accident in Chernobyl amounted to about 2 mSv for persons in Germany living south the Danube and in the rest of Germany about 0.6 mSv in the period from 1986 to 2030.

Fast breeder reactor

Nuclear reactor with a chain reaction maintained by fast neutrons and generating more fissile material than it consumes. The fertile material U-238 is converted into the fissile material Pu-239 by neutron capture and two subsequent beta decays. The nuclear fission is effected to obtain a high breeding effect, practically exclusively with fast neutrons. Since the neutrons should be decelerated as little as possible, water is excluded as a coolant due to its decelerating effect. For technical reasons, sodium, which is liquid above temperatures of 97.8 °C, is particularly well suited. The fast breeder can utilize the uranium up to 60 times better than the light water reactors.

Fast fission factor

Number of fast neutrons generated in a nuclear reactor by all fissions to the number of fast neutrons generated by thermal fission.

Fast reactor

Reactor in which the fission chain reaction is maintained mainly by fast neutrons. Fast reactors have no moderator since deceleration of the fast fission neutrons generated during the fission must be avoided.

FBR

→fast breeder reactor

FE

→fuel element

Federal Office for Radiation Protection

The Federal Office for Radiation Protection is an independent federal authority in the portfolio of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The Federal Office for Radiation Protection is responsible for administrative tasks of the Federal Government in the fields of radiation protection including radiation protection precaution and nuclear safety, the transport of radioactive substances and the disposal of radioactive waste, including the construction and operation of facilities of the Federal Government for the safe storage and ultimate waste disposal of radioactive waste. The Federal Office for Radiation Protection supports the Federal Minister for the Environment, Nature Conservation and

Nuclear Safety regarding technical and scientific aspects in the aforementioned fields, in particular in exercising the federal supervision, the elaboration of legal and administrative regulations and co-operation between the Länder. The Federal Office for Radiation Protection is engaged in scientific research to perform its tasks.

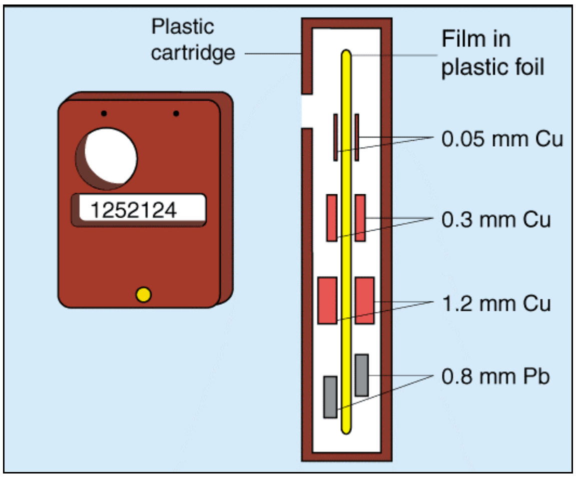
Fertile material

Non-fissionable material from which fissionable material is generated by neutron absorption and subsequent nuclei conversions. Fertile materials are thorium-232 which can be converted into fissionable uranium-233, and uranium-238 which can be converted into fissionable plutonium-239.

Th-232 + n ⇒ Th-233 ⇒ Pa-233 ⇒ U-233
U-238 + n ⇒ U-239 ⇒ Np-239 ⇒ Pu-239.

Film dosimeter

Measuring device to determine the dose. The blackening of a photographic film due to radiation is the measure of the dose received. The film cartridge holds various „filters“ made of different materials to determine the type and intensity of rays and other factors important to determine the dose.



Film dosimeter, front view and cross-section

Final energy

Form of energy available to the user following the conversion from primary energy carriers - crude oil, natural gas, nuclear energy, coal, regenerative energies. Final forms of energy include, among others, heating oil, fuels, gas, current, district heat.

Financial security

The administrative authority is required to fix the amount of the financial security for plants and operations where a nuclear liability pursuant to international obligations or the Atomic Energy Act is considered to meet the legal damage obligations which the applicant is required to assume. The financial security may be met by an insurance or by an indemnity or warranty obligation of a third party. The financial security sum amounts to approx. Euro 2,500 million for reactors with an electrical output of 1 300 MW. Without prejudice to the determination of this financial security the liability of the owner of the plant is, however, unlimited.

Fissile material

Any substance which can be fissioned by neutrons, during which further neutrons are released, e.g. U-235, Pu-239.

Fissile material flow control

→nuclear material monitoring

Fissility

Property of a nuclide to be fissioned by a nuclear process.

Fission

→nuclear fission

Fission chamber

Neutron detector with good discrimination towards other radiation types. In fissile material located within a gas ionization detector, e.g. an ionization chamber, neutrons initiate fissions. The energy-rich fission products create voltage pulses due to their high ionization density which can be well distinguished from the background.

Fission gas

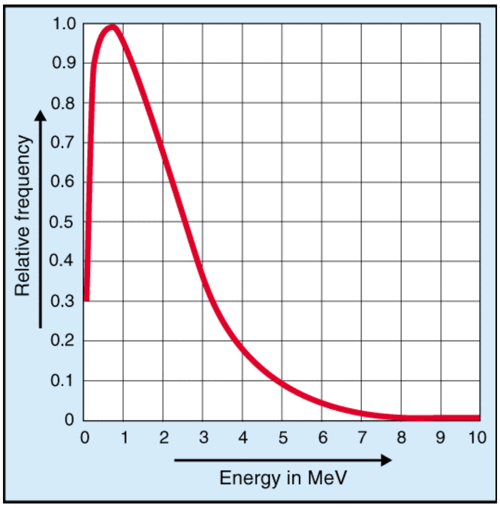
Gaseous fission products generated in nuclear fission, e.g. Kr-85.

Fission gas plenum

Clearance in the upper part of each →fuel rod to gather the fission gas generated during nuclear burnup.

Fission neutron

Neutrons resulting from the fission process having retained their original energy.



Energy distribution of the neutrons generated during the fission of U-235

Fission neutron yield

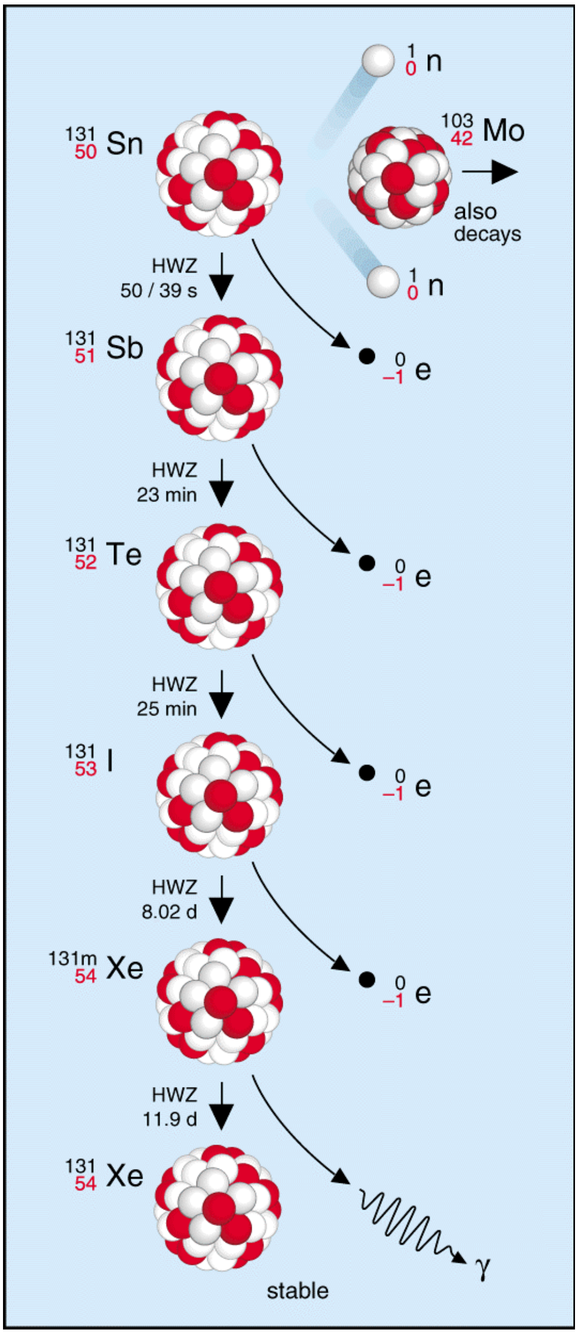
Ratio of average number of fission neutrons to the total number of neutrons absorbed in the fuel.

Fission product poison

→nuclear poison which is a fission product; e.g. Xe-135.

Fission products

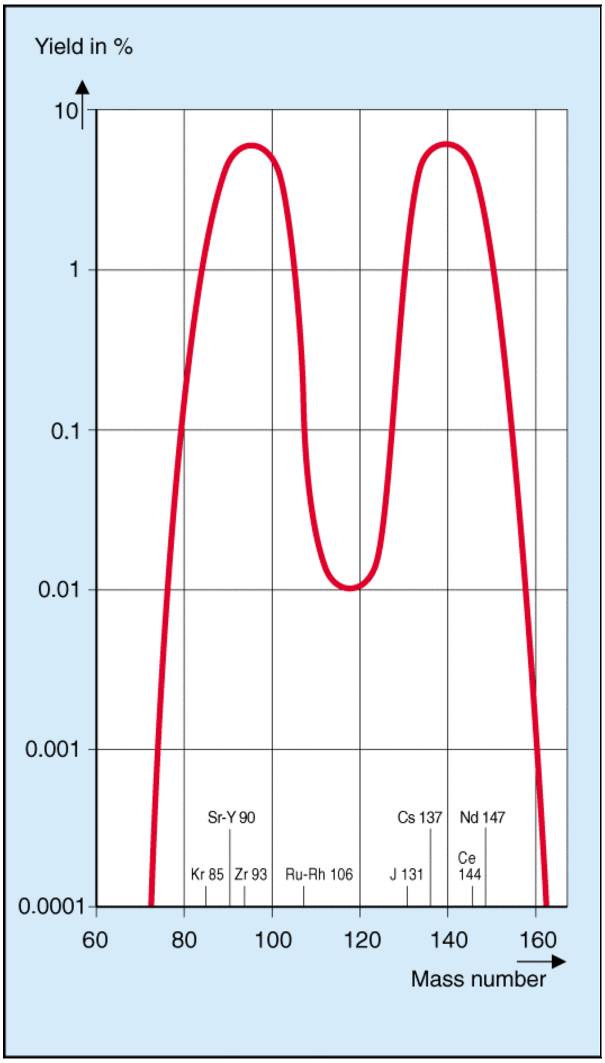
Nuclides generated by fission or subsequent radioactive decay of nuclides directly generated by fission; e.g.: Kr-85, Sr-90, Cs-137.



Decay chain of the primary fission product Sn-131

Fission yield

Percentage of a nuclide of the fission products occurring in a nuclear fission. Fission products with mass numbers around 90 and 140 have particularly high fission yields.



Fission yield, frequency distribution of the fission products generated in the fission of U-235

Fission, spontaneous

Property of very heavy atomic nuclei to fission without external excitation; mostly superimposed by other decay types. The half-life for spontaneous fission in the case of U-238 amounts to $8{\cdot}10^{15}$ years, i.e. one nucleus per gram U-238 converts by spontaneous fission about every 2.5 minutes . (The half-life of U-238 for alpha decay, in comparison, amounts to „only“ $4.5{\cdot}10^{9}$ years, therefore about 750 000 uranium atoms per gram U-238 convert by alpha decay per minute.) Cf-254 and Fm-256 convert almost exclusively by spontaneous fission.

Fission, thermal

Nuclear fission by thermal neutrons. →neutrons, thermal

Fissium, simulated

Mixture of substances made up of non-radioactive isotopes of elements which result as radioactive fission products during nuclear fission in order to be able to carry out investigations of the chemical and physical behaviour of this mixture without radiation protection measures.

FMRB

Forschungs- und Meßreaktor Braunschweig, research and measuring reactor in Brunswick of the Physikalisch-Technische Bundesanstalt (national metrology institute which performs scientific and technical services); pool reactor with a thermal output of 1 MW. Commissioning on 3rd Dec. 1967. Shutdown to prepare decommissioning in December 1995.

FORATOM

European Atomic Forum with its head office in Brussels, the parent organization of atomic forums of 13 European countries founded on 12th July1960.

FR 2

First reactor in the Federal Republic of Germany built on the basis of a national concept and independently in the Research Centre Karlsruhe. The FR 2 was a D_2O-moderated and cooled research reactor using UO_2 enriched to 2% as a fuel and with a power of 44 MW. The reactor entered operation on 7th March 1961. Following 20 years of operation without considerable malfunctions the FR 2 was finally shutdown on 21st Dec. 1981. The aim of the decommissioning measure - the safe inclusion of the reactor unit - and the disassembly of all residual systems was reached in November 1996.

FRG-1

Forschungsreaktor Geesthacht, research reactor of the GKSS Research Centre Geesthacht; pool reactor with a thermal output of 5 MW. Commissioning on Oct 23, 1958, final shutdown on June 28, 2010.

FRG-2

Forschungsreaktor Geesthacht, research reactor of the GKSS Research Centre Geesthacht; pool reactor with a thermal output of 15 MW. Commissioning on March 15, 1963, final shutdown on June 1, 1993

FRH

Forschungsreaktor Hannover, research reactor of the TRIGA-Mark 1 type of the Medical University in Hanover with a thermal output of 250 kW. Commissioning on 31st Jan. 1973. Final shutdown 18th December 1996. Decommissioning completed on 13th March 2008.

FRJ-1

Research reactor of the Research Centre Jülich; swimming pool reactor with a thermal output of 10 MW. Commissioning on 24th Febr. 1962. Final shutdown on 22nd March 1985, decommissioning completed on 8th Sept., 2008

FRJ-2

Research reactor of the Research Centre Jülich; heavy-water-moderated and cooled tank reactor with a thermal output of 23 MW. Commissioning on 14th Nov. 1962. Final shutdown on 2nd May 2006, decommissioning license granted 20th September, 2012

FRM

Forschungsreaktor München; light-water-moderated pool-type research reactor put into operation on 31st Oct. 1957 as the first reactor in Germany. Final shutdown on 28th July 2000 to prepare decommissioning.

FRM II

The new high-flux neutron source FRM-II is constructed as a reactor to replace the Munich Research Reactor FRM which has been in operation since 1957. First criticality on 2nd March 2004, full power on 24th August 2004. Based on its sophisticated technical concept, the FRM-II will achieve a useable neutron flux 50 times higher at a reactor power (20 MW) five times higher than that of the FRM. A large-scale heavy-water-moderator tank is used to establish this high flux in a considerably greater usable volume and practically only by slow neutrons which are particularly well suited for utilization.

FRMZ

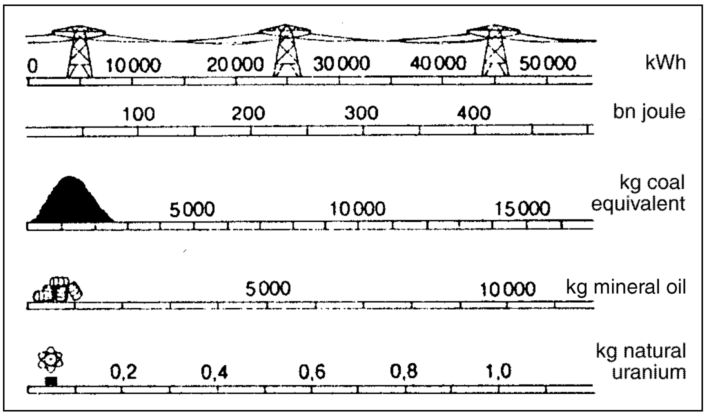
Forschungsreaktor Mainz, TRIGA-MARK II research reactor of the Institut für Kernchemie (Institute for Nuclear Chemistry) of the university of Mayence with a thermal output of 100 kW. Commissioning on 3rd Aug. 1965.

Fuel

→nuclear fuel

Fuel comparison

With a complete combustion or fission, approx. 8 kWh of heat can be generated from 1 kg of coal, approx. 12 kWh from 1 kg of mineral oil and around 24 000 000 kWh from 1 kg or uranium-235. Related to one kilogram, uranium-235 contains two to three million times the energy equivalent of oil or coal. The illustration shows how much coal, oil or natural uranium is required for a certain quantity of electricity. Thus, 1 kg natural uranium - following a corresponding enrichment and used for power generation in light water reactors - corresponds to nearly 10 000 kg of mineral oil or 14 000 kg of coal and enables the generation of 45 000 kWh of electricity.



Comparison of the input volumes of various primary energy carriers for the generation of a certain quantity of electricity

Fuel cycle

→nuclear fuel cycle

Fuel element

Arrangement of a number of →fuel rods into which the nuclear fuel is inserted in the reactor. A fuel element of a pressurized water reactor contains about 530 kg, that of a boiling water reactor about 190 kg of uranium. The pressurized water reactor of the Emsland nuclear power plant uses 193 fuel elements and the Krümmel boiling water reactor 840.

Fuel element, irradiated

→fuel element, spent

Fuel element, spent

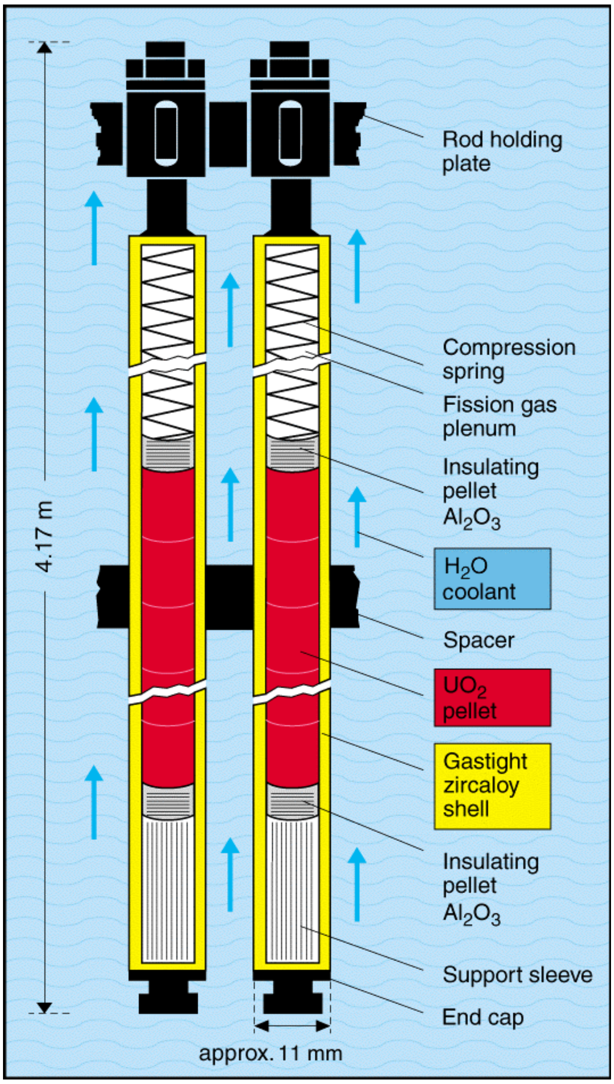
Fuel element after its use in the reactor; also called irradiated fuel element.

Fuel reprocessing

The chemical treatment of nuclear fuel after its use in a reactor to remove the fission products and to recover the unused uranium and the new fissile material plutonium generated during the fission. →reprocessing

Fuel rod

Geometrical form in which nuclear fuel surrounded by cladding material is inserted into a reactor. Several fuel rods are normally compiled into a fuel element. In the Krümmel Nuclear Power Plant with a boiling water reactor, 72 fuel rods form a fuel element, in the pressurized water reactor of the Emsland Nuclear Power Plant a fuel element contains 300 fuel rods.



Fuel rod

Fuel, ceramic

High-temperature resistant nuclear fuel in ceramic form, e.g. oxides, carbides, nitrides.

Fusion

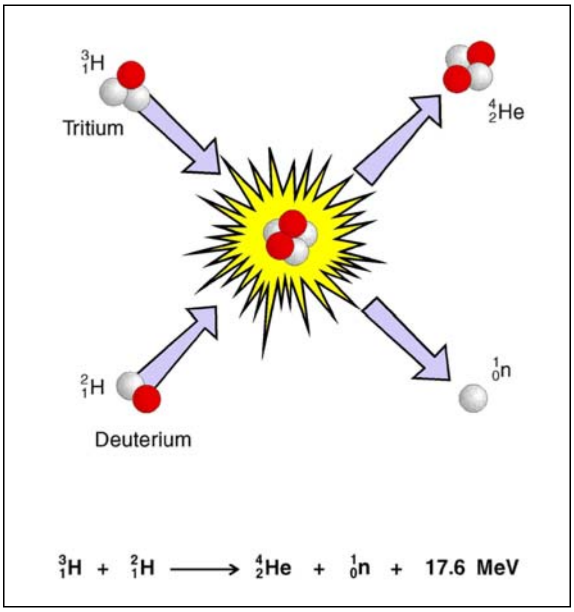
Formation of a heavy nucleus from lighter nuclei releasing energy - the binding energy. Possible fusion reactions:

$D + T \rightarrow {}^4He + n + 17.58$ MeV,
$D + D \rightarrow {}^3He + n + 3.27$ MeV,
$D + D \rightarrow T + p + 4.03$ MeV,
$D + {}^3He \rightarrow {}^4He + p + 18.35$ MeV,
$p + {}^{11}B \rightarrow 3\,{}^4He + 8.7$ MeV.

The deuterium-tritium reaction is the easiest to realize among all possible fusion reactions. Deuterium is available in sufficient quantity in the oceans of the world; tritium can be "bred" from the lithium element - which is also available in abundance - by means of the neutrons generated during the fusion process.

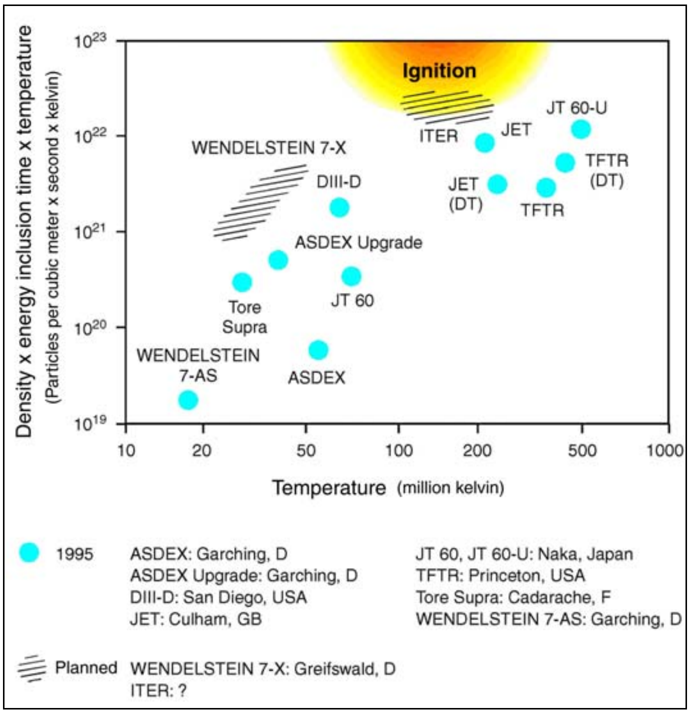
Breeding reactors for the generation of tritium from lithium:

$^{7}Li + n \rightarrow {}^{4}He + T + n - 2.47$ MeV,
$^{6}Li + n \rightarrow {}^{4}He + T + 4.78$ MeV.



Fusion principle

During fusion, two atomic nuclei - e.g. nuclei of the hydrogen isotopes deuterium and tritium - must be brought so close together that they fuse in spite of the repellent electric power of their positive nucleus charges. Two nuclei must fly against each other with high speed to overcome their mutual repulsion. The required speeds of the particles are achieved at high temperatures of about 100 million degrees. The atoms of a gas subsequently disintegrate into electrons and nuclei and the gas is ionized. A completely ionized gas is called plasma. Plasma is electrically conductive and its motion can therefore be influenced by electric and magnetic fields. Advantage is taken of this fact in fusion facilities where the hot plasma is enclosed by a magnetic field cage. In a magnetic field, the Lorentz force acts on the charge carriers. As a result of this force, the charge carriers perform a spiral movement along the magnetic field lines. Ideally, a contact with the container wall and thus heat transport to the wall can be prevented. As arrangements to magnetically enclose the plasmas within a ring the systems of the type →Tokamak and →stellarator are usual. →JET, →ITER. The main research target in plasma physics is to find a suitable procedure allowing a controlled fusion reaction in the form of a chain reaction that enables use of the released energy. During the fusion of deuterium and tritium to form 1 kg helium, an energy of about 120 million kWh is released corresponding to a gross calorific value of 12 million kilograms of coal.



Fusion experimental facilities and the plasma conditions reached by them

G

Gamma quantum

Energy quantum of short-wave electromagnetic radiation.

Gamma radiation

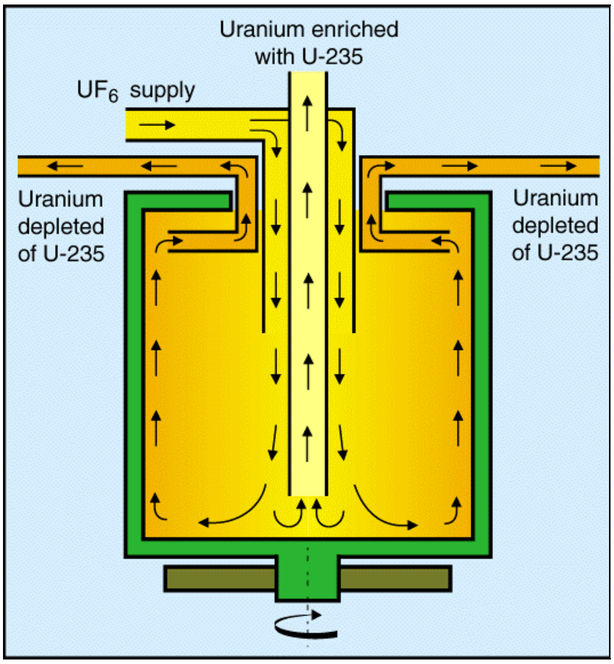
Highly-energetic, short-wave electromagnetic radiation emitted from the nucleus of an atom. Gamma radiation energies usually range between 0.01 and 10 MeV. X-rays also occur within this energy range; they originate, however, not from the nucleus, but are generated by electron transfers in the electron sheath or by electron deceleration in matter (bremsstrahlung). In general, alpha and beta decays and always the fission process are accompanied by gamma radiation. Gamma rays are extremely penetrative and may best be weakened by material of high density (lead) and high atomic number.

Gas amplification

Increase in the number of charge carriers caused by impact ionization in a proportional and Geiger-Müller counter.

Gas centrifuge process

Process to separate isotopes in which heavy atoms are split from the lighter atoms by centrifugal forces. The →separation factor depends on the mass difference of the isotopes to be separated. The process is suitable for the separation of uranium isotopes, the achievable separation factor amounts to 1.25. A uranium enrichment plant applying this process is operated in Gronau/Wesphalia.



Principle of a gas centrifuge process for uranium enrichment

Gas-cooled reactor

Nuclear reactor cooled with gas (helium, carbon dioxide).

Gaseous diffusion process

→diffusion separation process

Gas flow counter

A →proportional counter with its flowing filling gas continuously replaced by new gas. Thus, the ingress of air is avoided or ingressed air expelled.

Geiger-Müller counter

Radiation detection and measuring device. It consists of a gas-filled tube in which an electric discharge takes place when it is penetrated by ionizing radiation. The discharges are counted and signify a measure for the radiation intensity.

Geometrically safe

Term from reactor engineering; geometrically safe signifies a system containing fissile material in which no self-perpetuating chain reaction may take place due to its geometric arrangement.

GeV

Gigaelectron volt; 1 GeV = 1 billion eV; →electron volt.

GKN-1

Gemeinschaftskernkraftwerk in Neckarwestheim/Neckar, unit 1, pressurized water reactor with an electric gross output of 840 MW (including 157 MW for railway current), nuclear commissioning on 26th May 1976, final shutdown on 16th March 2011. Lifetime electricity generation: 186 TWh.

GKN-2

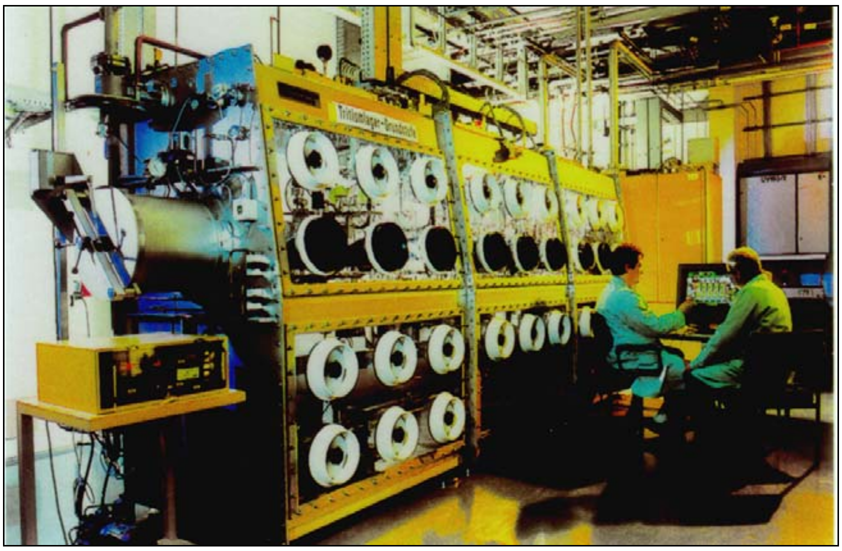
Gemeinschaftskernkraftwerk in Neckarwestheim/Neckar, unit 2, pressurized water reactor with an electric gross output of 1365 MW, nuclear commissioning on 29th Dec. 1988.

Glass dosimeter

→phosphate glass dosimeter

Glove Box

Gas-tight box mostly made of transparent synthetic material in which certain radioactive substances, e.g. tritium or plutonium, can be handled without danger by means of gloves reaching into the box.



Laboratory for the handling of gaseous tritium in a row of glove boxes

Gonad dose

Radiation dose at the gonads (testicles and ovaries).

Gorleben

Location of several nuclear facilities in Lower Saxony. At the Gorleben location, an interim storage facility for spent fuel elements and a storage facility for low active waste from nuclear power plants are operated. A conditioning plant for the preparation and packaging of spent fuel elements for direct ultimate waste disposal is largely complete. For the repository of the Federal Government for radioactive waste, including high active heat-generating waste - glass canisters with waste from reprocessing, conditioned irradiated fuel elements for direct ultimate waste disposal - underground reconnaissance for the suitability of the salt dome has been carried out. This reconnaissance has currently been suspended by the Federal Government.

Gray

Name for the unit of absobed dose, symbol: Gy. 1 Gray = 1 joule divided by kilogram. The name has been chosen in memory of Louis Harold Gray (1905 to 1965) who contributed to the fundamental findings in radiation dosimetry.

Ground radiation

→terrestrial radiation, also gamma radiation emitted by radioactive deposits on the ground due to disposal with the exhaust air from nuclear facilities.

GRS

→Company for Industrial Plants and Nuclear Safety.

GW

Gigawatt, one billion times the power unit of watt; 1 GW = 1 000 MW = 1 000 000 kW = 1 000 000 000 W.

Gwe

Gigawatt electric; 1 GWe = 1 000 MWe = 1 000 000 kWe.

Gy

Symbol for the absobed dose unit →gray.

H

Hafnium

Metal; neutron absorber which is mainly effective in the thermal and epithermal neutron energy range. Hafnium is preferably used as a heterogeneous neutron poison to avoid criticality incidents; high radiation and corrosion resistance.

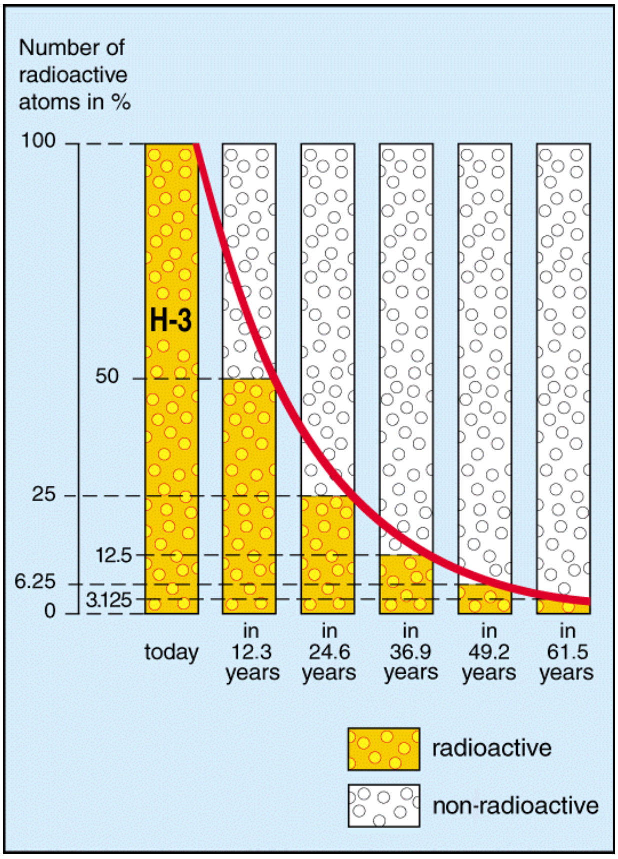
Half-life

The period during which half of the nuclei decay in a quantity of radionuclides. There are extreme variations in the half-lives of the various radionuclides, e.g. from $7.2 \cdot 10^{24}$ years for tellurium-128 down to $2 \cdot 10^{-16}$ seconds for beryllium-8. The following relations exist between the half-life T, the →decay constant λ and the average →lifetime:

$T = \lambda^{-1} \cdot \ln 2 \approx 0.693 / \lambda$

$\lambda = T^{-1} \cdot \ln 2 \approx 0.693 / T$

$\tau = \lambda^{-1} \approx 1.44\ T$



Decay curve of tritium (H-3), Half-life 12.3 years

Half-life, biological

The period during which a biological system, for instance a human being or animal, naturally excretes half of the absorbed quantity of a certain substance from the body or a specific organ. For adults the following biological half-lives apply:

- Tritium (whole body): 10 days,
- Caesium (whole body): 110 days,
- Iodine (thyroid gland): 80 days,
- Plutonium: 20 years (liver), 50 years (skeleton).

Half-life, effective

The period during which the quantity of a radionuclide in a biological system is reduced by half by interaction of radioactive decay and excretion due to biological processes.

$$T_{eff} = \frac{T_{phys} \cdot T_{biol}}{T_{phys} + T_{biol}}$$

T_{phys}: physical half-life
T_{biol}: biological half-life

The table indicates the physical, biological and resulting determined effective half-life of some radionuclides for adults.

Nuclide	Physical half-life	Biological half-life	Effective half-life
Tritium	12.3 a	10 d	10 d
Iodine-131	8 d	80 d	7.2 d
Caesium-134	2.1 a	110 d	96 d
Caesium-137	30.2 a	110 d	109 d
Plutonium-239	24100 a	50 a	49.9 a

Half-lives for some radionuclides

Half-value thickness

Layer thickness of a material reducing the intensity of radiation by absorption and scattering by half.

Halogen-quench Geiger tube

→Geiger-Müller counter in which a few percent of a halogen, Cl_2 or Br_2, have been added to the argon or neon counting gas, to achieve self-quenching of the gas discharge.

Handling of radioactive substances

Handling of radioactive substances comprises: obtaining, production, storage, treatment, processing, other application and elimination of radioactive substances in the sense of the Atomic Energy Act, and the operation of irradiation facilities. Handling also involves prospecting, mining and conditioning of radioactive mineral resources in the sense of the Federal Mining Act.

Harrisburg

The Three Mile Island Nuclear Power Plant with two pressurized water reactors is located near Harrisburg, Pennsylvania, USA. On 28th March 1979, a serious accident with partial core meltdown occurred in unit 2. The fission products were almost completely retained in the reactor pressure vessel and in the containment. Since the retention function of the containment functioned as designed, only xenon-133 and very small proportions of I-131 were released into the environment, resulting in a calculatory maximum dose of 0.85 mSv.

HAW

High **A**ctive **W**aste

HDR

Heißdampfreaktor (superheated steam reactor) Großwelzheim/Main, boiling water reactor with integrated nuclear superheating with an electric gross output of 25 MW, nuclear commissioning on 14th Oct. 1969. Shut down since April 1971. The plant was used for many years following the shutdown for research projects relating to reactor safety. The dismantling of the plant has been completed and the „green meadow“ condition restored.

Head-end

Term from reprocessing technology; the first process step of reprocessing. The head-end comprises all process stages of mechanical sectioning of fuel elements up to chemical dissolution of the spent fuel in order to prepare extraction. The individual steps are: the fuel elements are fed into a sectioning machine which cuts the fuel element bundles or the individual fuel rods after singularization into approx. 5 cm long pieces. To dissolve the irradiated fuel, the fuel rod pieces fall into a dissolution device where uranium, plutonium and fission products are dissolved in concentrated nitric acid. Once the dissolution process is finished, the fuel solution is purified of solid particles by filtering or centrifuging and passed to a buffer container for assessment of the uranium and plutonium content. Zircaloy, the cladding material of the fuel rods resistant to nitric acid remains in the dissolution device. →tail-end

Heavy hydrogen

→deuterium

Heavy water

Deuterium oxide, D_2O; water containing two deuterium atoms instead of the two light hydrogen atoms. Natural water contains one deuterium atom per 6500 molecules H_2O. D_2O has a low neutron absorption cross-section. It is therefore applicable as a moderator in natural-uranium-fuelled reactors.

Heavy-water reactor

Reactor cooled and/or moderated with heavy water (D_2O). Example: →CANDU reactors; D_2O pressurized water reactor Atucha, Argentina.

HEPA filter

High-**e**fficiency **p**articulate **a**ir filter to separate dry aerosols; in Germany suspended matter filter of special class S, frequently called „absolute membrane filter“.

Heterogeneous reactor

Nuclear reactor in which the fuel is separated from the moderator. Opposite: →homogenous reactor. Most reactors are heterogeneous.

HFR

High-Flux Reactor; research reactor in ILL in Grenoble. Maximum neutron flux density: $1.5 \cdot 10^{15}$ neutrons/cm^2 s, power: 57 MW.

High-temperature reactor

The High-Temperature Reactor (HTR) has been developed in Germany as a →pebble bed reactor. The pebble bed core consists of spherical fuel elements surrounded by a cylindrical graphite vessel used as a neutron reflector. The fuel elements with a diameter of 60 mm are made of graphite in which the fuel is embedded in the form of many small coated particles. The pyrocarbon and silicon carbide coating of the fuel particles retains the fission products. The reactor is fed continuously with the fuel element during power operation. Helium as a noble gas is used to cool the reactor core. Depending on the application purpose, the helium flowing through the pebble bed is heated to 700 to 950 °C. All components of the primary helium circuit are enclosed in a reactor pressure vessel designed as a prestressed concrete vessel for a power of more than 200 MW. The high-temperature reactor is a universally usable energy source providing heat at high temperatures up to 950 °C for the electricity and overall heat market. A further target of HTR development is direct use of the heat generated by nuclear reaction at high temperatures for chemical processes, in particular coal gasification. The AVR Experimental Nuclear Reactor in Jülich was the first German HTR in operation between 1966 and 1988. It confirmed the technology of the pebble bed reactor and its suitability for power plant operation. Long-term operation at a helium temperature of 950 °C proved the suitability of the HTR as a process heat reactor. The THTR 300 Prototype Nuclear Power Plant in Hamm-Uentrop was the second German project in power operation between 1985 and 1988.

Homogeneous reactor

Reactor in which the fuel is a mixture with the moderator or coolant. Liquid homogenous reactor: e.g. uranium sulphate in water; solid homogeneous reactor: e.g. mixture of uranium (UO_2) in polyethylene.

Hot

A term used in nuclear technology for „highly active“.

Hot cell

Highly shielded tight casing in which highly radioactive substances can be remotely handled by manipulators observing the processes through lead-glass windows so that there is no hazard to personnel.

Hot cells, operator side with manipulators for remote-controlled work

Hot laboratory

Laboratory designed for the safe handling of highly radioactive substances. It generally contains several hot cells.

Hot workshop

Workshop for the repair of radioactively contaminated components from controlled areas. Conventional equipment, however, working areas graduated according to radiation protection aspects in compliance with the allocation of radiation protection zones.

HTR

→high-temperature reactor

Hydrogen bomb

Nuclear weapon using the energy release of nuclear fusion reactions. Probably, the reactions $^{6}Li\ (n,\alpha)\ ^{3}H$ + 4.8 MeV and $^{3}H\ (d,n)\ ^{4}He$ + 17.6 MeV are involved. An atomic bomb is used to fire the hydrogen bomb, i.e. to reach the temperature required for fusion. The explosion force achievable far surpasses that of atomic bombs, the destruction equivalent is that of several megatonnes trinitrotoluene, a chemical explosive. The first hydrogen bomb was fired on the Bikini Atoll on 1st March 1954.

Hydrogen sulphide process

Process to obtain heavy water utilizing the negative temperature dependence of the equilibrium constants of the reaction $H_2S + HDO \Leftrightarrow HDS + H_2O$. The hydrogen sulphide enriched with deuterium at high temperature releases part of the deuterium at low temperature to the water. In the countercurrent process between a hot and a cold column, deuterium enrichment results between the columns.

Hyperons

Group of short-lived elementary particles, the mass of which is greater than that of a neutron. →elementary particle

I

IAEA

International Atomic Energy Agency, Vienna.

ICRP

→International Commission on Radiological Protection

ICRU

International Commission on Radiological Units and Measurements

IK

→Informationskreis Kernenergie

ILL

Institut Max von Laue - Paul Langevin, Grenoble.

Imission

Effects of air pollution, noise and vibration on human beings, animals and vegetation.

Incident

Sequence of events, on occurrence of which plant operation or activity cannot be continued for safety reasons. A plant must be designed taking account of the incident or provide safety precautions against the incident.

Incident/accident levels

The notifiable events in nuclear facilities in Germany are classified on different levels in accordance with →AtSMV corresponding to their importance with respect to safety.

- Level S: This level comprises such events which must be reported immediately to the damage inspection officials so that they can initiate examinations at short notice or cause measures to be taken. These events also include those presenting acute safety-related defects.
- Level E: This level comprises such events in which - although they do not require immediate measures to be taken by the damage inspection officials - the cause must be clarified and remedied in adequate time. These include for example events that are potentially significant - but not immediately so - from the point of view of safety.
- Level N: This level comprises events of general relevance to safety about which the damage inspection officials must be notified. These generally include events beyond routine operational events which are important regarding safety criteria (assurance of optimally incident-free and environmentally compatible operation of the plant; sufficiently reliable avoidance of incidents by adequate design, quality and operation of the plant).
- Level V: This level comprises all events in a nuclear power plant prior to the loading with nuclear fuel about which the damage inspection officials must be notified with regard to subsequent safe operation of the plant.

The International Atomic Energy Organisation has prepared an International Nuclear Event Scale (→INES) for important events in nuclear installations which is also applied in Germany in addition to the aforementioned reporting levels.

Incident precautions

The nuclear licensing of nuclear facilities commits the operator to take precautions against incidents and protective measures. Together with the governmental disaster control plan, the incident precautions comprise all measures to reduce the effects of incidents and accidents on the environment.

Incident probability analysis

Methodical analysis to examine the possibility and probability of the occurrence of incidents and accidents based on event and fault trees.

Incident sequence analysis

Methodical examination of the sequence of an incident. The incident sequence analysis is used to determine physical, chemical and technical processes during the course of an incident as well as to establish its effect regarding type and quantity of radionuclides released during the incident. The possible conclusions on the quality of the examined technical system based on the incident sequence analysis generally result in measures designed to increase system safety and reliability.

Incorporation

General: intake in the body. Specific: intake of radioactive substances into the human body.

Indicator

Element or compound made radioactive for easy tracing in biological, chemical and industrial processes. The radiation emitted by the radionuclide subsequently shows its position and distribution.

Inert gas

Non-flammable gas, e.g. CO_2, nitrogen, noble gases. Inert gas is used in manufacturing facilities with flammable substances for inerting unmanned process rooms as an active and passive fire protection measure.

INES

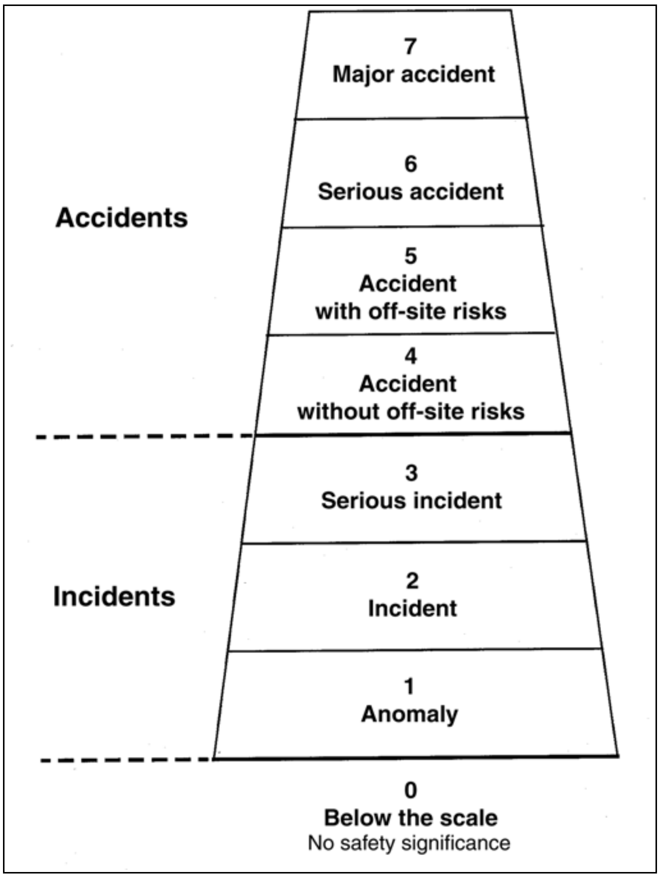
International **N**uclear **E**vent **S**cale; a scale with seven levels proposed by the IAEO to evaluate the events occurring in nuclear installations according to international uniform criteria, in particular with regard to the aspect of hazards to the population. The upper levels (4 to 7) include accidents, the lower levels (1 to 3) anomalies and incidents. Notifiable events of no safety-related or radiological significance according to the international scale are designated as „below the scale“ or „Level 0“. The events are evaluated according to three overriding aspects:

„Radiological effects outside the installation“,

„Radiological effects inside the installation“ and

„Impairment of safeguards“.

The first aspect comprises events which lead to release of radioactive substances into the environment of the installation. The highest level corresponds to a catastrophic accident in which health and environmental consequences over a wide area are to be expected. The lowest level of this aspect - Level 3 - corresponds to a very low level of radioactivity release resulting in radiation exposure that amounts to about one tenth of natural radiation for the most severely affected persons outside the installation. The second aspect comprises Levels 2 to 5 and concerns the radiological effects inside the installation, i.e. ranging from serious damage at the reactor core to greater contaminations within the installation and impermissible high radiation exposure of the staff. The third aspect - assigned to Levels 0 to 3 - comprises events in which safeguards designed to prevent the release of radioactive substances have been impaired.



INES scale to classify events in nuclear installations

Informationskreis KernEnergie

Founded in 1975 by operators and manufacturers of nuclear power plants, the organization is made up of representatives from different institutions and bodies, including scientists from independent institutions for environmental and safety research, in addition to representatives of electric utilities. The Informationskreis KernEnergie (IK) objectifies the discussion about the peaceful use of nuclear energy by providing facts and indicates prospects of a reliable energy supply, holds continuous discussions with the general public and promotes public acceptance. Address: Informationskreis KernEnergie, Robert-Koch-Platz 4, 10115 Berlin.

Ingestion

Intake of - radioactive - substances through food and drinking water.

Inhalation

Intake of - radioactive - substances with breathed in air.

Inherently safe

A technical system is called inherently safe if it functions safely by its own means, i.e. without auxiliary media, auxiliary energy and active components. For example, a cooling-water system provides inherently safe cooling if heat is removed via sufficiently large heat exchangers with gravity circulation of the cooling water (natural convection), since gravity is always available.

INIS

International Nuclear Information System of IAEO

In-pile

Term to denote experiments or devices within a reactor.

Intake

→activity intake

Integrity under aircraft crash

Nuclear facilities such as nuclear power plants must be constructed safe for aircraft crashes pursuant to the valid safety regulations. Examinations have showed that the risk to the facilities depends on fast flying military aircraft. To ensure that the aircraft does not penetrate walls and ceilings, wall thicknesses of about 1.5 m reinforced concrete are required. The calculations are based on the crash of a Phantom RF-4E. It has been checked that this wall thickness is also sufficient for Jumbo jet crashes involving for example a Boeing 747 where even less thick walls would be sufficient due to the lower crash speed and the larger impact surface. The safety precautions also consider the consequences of an aircraft crash such as fuel fire and fuel explosion or missile effects.

Interaction

Influence of a physical body on another body or the coupling between a field and its source. Interactions can be of the most diverse types, e.g. gravitational interaction, electromagnetic interaction, weak interaction, strong interaction.

Interaction, strong

It results in the binding forces of the nucleons in the atomic nucleus. In addition to the electromagnetic and the weak interaction, it is the third known interaction between elementary particles. The strong interaction behaves towards the electromagnetic, the weak and the gravitational interaction as

$$1 : 10^{-3} : 10^{-15} : 10^{-40}.$$

Interaction, weak

Interaction between elementary particles where the parity is not maintained, e.g. beta decay.

Interim storage facilities for fuel elements

Storage buildings for the temporary storage of spent fuel elements for the period between removal from the nuclear power plant and reprocessing or direct ultimate waste disposal. The elements are stored in specially designed cast-iron containers, in particular in so-called Castor® containers which meet all safety functions such as radiation shield, retention of radioactive substances, mechanical integrity even in the event of earthquakes and aircraft crashes. These containers are stored in conventional warehouses. The containers are cooled during interim storage by the natural convection of air. Interim storage facilities for spent fuel elements in Germany are located in Ahaus (North Rhine-Westphalia) with a storage capacity of 3,960 t spent nuclear fuel and in Gorleben (Lower Saxony) with a capacity of 3800 t. A further modified interim storage facility has been established in Lubmin (Mecklenburg-Western Pommerania), in particular for the storage of dismantled reactor unit components from the former Greifswald Nuclear Power Plant. Further interim storage facilities are to be built at the sites of the nuclear power plants.

Interim storage of spent fuel elements

In accordance with the disposal concept for nuclear power plants, waste from nuclear facilities is to be safely enclosed in repositories with no time limitation. These repositories are not yet available today. Until then the spent fuel elements are either transported to the two central interim storage facilities at Ahaus (North-Rhine Westphalia) and Gorleben (Lower Saxony) or to reprocessing plants abroad. To minimize these transports, the Federal Government requests the additional possibility to place spent fuel elements in interim storage facilities at the power plant site. For this purpose, site interim storage facilities are to be erected which can hold the fuel elements until their ultimate disposal in repositories in 30 to 40 years. The operators of nuclear power plants have filed licensing applications with the Federal Office for Radiation Protection for the erection of site interim storage facilities. For interim storage the fuel elements are packaged in special transport/storage containers (→Castor® containers) which are used both for the transport from the nuclear power plant to the interim storage facility and as a storage container. The 40 cm thick wall shields the radiation off, cooling fins at the outside of the container ensure safe heat dissipation of the heat generated by the decay of the fission products to the ambient air.

Intermediate load power plant

Power plant for electricity supply which, due to its operational and economic properties, is used to cover the intermediate load. Intermediate load power plants are coal- and gas-fired power plants. →load range

International Commission on Radiological Protection

The "International Commission on Radiological Protection", was founded under the name "International X-ray and Radium Protection Committee" upon the resolution of the 2nd International Congress for Radiology in 1928. In 1950 the commission was restructured and renamed. It co-operates closely with the International Commission for Radiological units and measurements (ICRU) and has official links to the World Health Organisation (WHO), to the International Labour Organisation (ILO) and other corporations of the United Nations, including the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the United Nations Environment Programme (UNEP) as well as the Commission of the European Communities, the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA), the International Standard Organisation (ISO), the International Electrotechnical Commission (IEC) and the International Radiation Protection Association (IRPA). The International Commission on Radiological Protection consists of a chairman, twelve further members and a secretary. The members are voted based on nominations by the ICRP submitted by the national delegations of the International Congress for Radiology and by its own members. The ICRP members are selected on the basis of their recognized performances in medical radiology, radiation protection, physics, medical physics, biology, genetics, biochemistry and biophysics.

Intervention threshold

Values of the body dose, activity intake, contamination or other activity or dose-related values for which, when exceeded, intervention in the normal operating or irradiation sequence is considered necessary.

Intervention

Operation in order to carry out maintenance work in plant sections with increased radiation. The intervention is prepared in consultation with radiation protection personnel and monitored during the process.

Iodine filter

Following precleaning by gas washing and/or wet aerosol separators, the off-gas containing iodine from nuclear facilities passes adsorbers (silver nitrate impregnated silica gel carriers or molecular sieve zeolites), which convert the iodine to iodic silver adhering to the carrier material by chemisorption, thereby filtering the iodine out of the off-gas.

Ion

Electrically charged atomic or molecular particle which can be generated from a neutral atom or molecule by electron separation or caption, or by electrolytical dissociation of molecules in solutions.

Ion dose

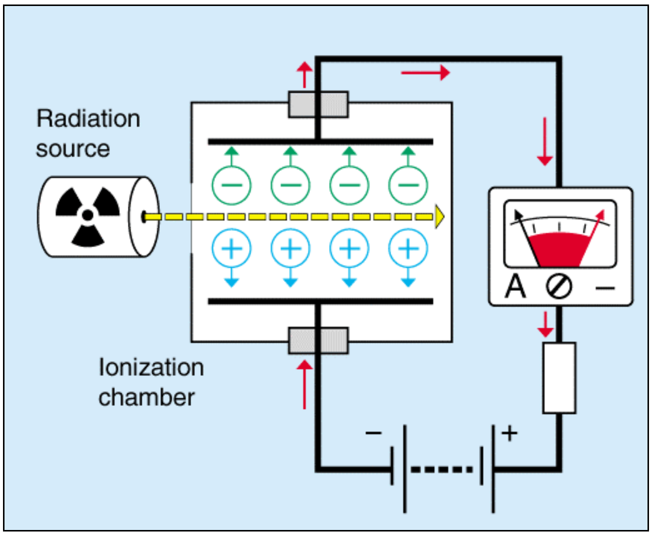
Former measuring variable used in dosimetry for ionizing radiation. The unit of the ion dose is coulomb divided by kilogram (C/kg). 1 coulomb divided by kilogram is equal to the ion dose generated during the generation of ions of a preceding sign with an electric charge of 1 C in air with a mass of 1 kg caused by ionizing radiation of energy flux density constant in space. By the end of 1985 the unit roentgen (symbol: R) was accepted. 1 roentgen is equal to 258 µC/kg.

Ion exchanger

Chemical substances (insoluble, mostly high-molecular polyelctrolytes) with functional anchor groups, the ions of which can be exchanged for other ions. Application: separation of substance mixtures.

Ionization chamber

Device for detection of ionizing radiation by measuring the electric current generated when radiation ionizes the gas in the chamber and therefore makes it electrically conductive.



Principle of an ionization chamber

Ionization

Absorption or emission of electrons by atoms or molecules, which are thereby converted to ions. High temperatures, electric discharges and energy-rich radiation may lead to ionization.

Ionizing radiation

Any radiation which directly or indirectly ionizes, e.g. alpha, beta, gamma, neutron radiation.

IRPA

International Radiation Protection Association; combination of national and regional radiation protection companies. Founded in 1966 to promote international contacts, co-operation and discussion of scientific and practical aspects in the fields of protection of people and environment against ionizing radiation. The IRPA has more than 20 000 members in 61 states.

Isobars

In nuclear physics, nuclei with the same number of nucleons. Example: N-17, 0-17, F-17. All three nuclei have 17 nucleons, the nitrogen nucleus (n) however 7, the oxygen nucleus (O) 8 and the fluorine nucleus (F) 9 protons.

Isodose curve

Geometric place for all points where the dose variable has the same value.

Isomers

Nuclides of the same neutron and proton numbers, however with different energetic conditions; e.g. the barium nuclides Ba-137 and Ba-137m.

Isotones

Nuclei of atoms with the same neutron number. Example: S-36, Cl-37, Ar-38, K-39, Ca- 40. These nuclei contain 20 neutrons each, but a different number of protons: sulphur 16, chlorine 17, argon 18, potassium 19 and calcium 20 protons.

Isotope

Atoms of the same atomic number (i.e. the same chemical element), however with a different nucleon number, e.g. Ne-20 and Ne-22. Both nuclei belong to the same chemical element neon (symbol: Ne) and therefore both have 10 protons each. The nucleon number is different since Ne-20 has ten neutrons and Ne-22 twelve neutrons.

Isotope enrichment

Process by which the relative frequency of an isotope in an element is increased. Example: enrichment of uranium at the uranium-235 isotope; →enriched uranium.

Isotope exchange

Processes leading to the alteration of isotope composition in a substance, e.g.: $H_2S + HDO \rightarrow HDS + H_2O$ (H = „normal“ hydrogen, D = deuterium, „heavy“ hydrogen, S = sulphur). The equilibrium is influenced by the different relative atomic masses.

Isotope laboratory

Work rooms where the spatial and instrumental equipment enables safe handling of open radioactive substances. Pursuant to IAEO recommendations, isotope laboratories are classified in three types according to the activity which they are allowed to handle: A, B and C. In this context, measurement of activity is a multiple of the free limit in accordance with the Radiation Protection Ordinance. Laboratory type C thus corresponds to a handling quantity of up to 10^2 times, laboratory type B up to 10^5 times and laboratory type A beyond 10^5 times the free limit. In type C laboratories, fume cupboards are to be installed when there is a risk of impermissible ambient air contamination. In general, exhaust air filtering is not required. In type B and A laboratories, provision is to be made for glove boxes or other working cells, in addition to fume cupboards, for the handling of open radioactive substances. Exhaust air filtering is required. Details are contained in DIN 25 425.

Isotope separation

Process to separate individual isotopes from isotope mixtures; →electromagnetic isotope separation, →diffusion separation process, →nozzle separation process, →gas centrifuge process, →isotope exchange.

Isotopic abundance

Quotient of a number of atoms of a certain isotope in an isotope mixture of an element and the number of all atoms of this element.

Isotopic abundance, natural

Isotope frequency in a naturally occurring isotope mixture. In nature, elements for which several isotopes exist occur in an isotope mixture that - apart from a few specifically justified exceptions - is the same everywhere on earth. Several isotopes may occur in about the same ratio, e.g. Cu-63 with 69% and Cu-65 with 31% in the case of copper. However, one isotope frequently predominates and the others are present only in traces in this case, e.g. for oxygen: 99.759% O-16; 0.0374% O-17; 0.2039% O-18.

Isotopic dilution analysis

Method for the quantitative determination of a substance in a mixture by adding the same, but radioactive substance. The quantity of the test substance can be calculated based on the change in specific activity of the added radioactive substance.

ITER

The major international fusion programmes - People's Republic of China, European Union, India, Japan, Republic of Korea, Russian Federation, USA - co-operate in the ITER project for the construction of an International Thermonuclear Experimental Reactor (ITER). The ITER is intended to demonstrate that it is physically and technically possible to simulate on earth the energy generation of the sun and to obtain energy by nuclear fusion. ITER is intended to create long-term energy-delivering plasma for the first time. The scientific co-operation was initiated in 1985. In 1998, the final report was passed to the ITER partners. The partners decided to review the ITER draft with a view to cost saving. The cost-reduced draft was approved in January 2000. The planning work based on the preliminary draft was completed in July 2001. ITER construction started in 2009 at Cadarache, France, Approximately ten years after the construction licence ITER would be able to generate the first plasma. Its data are:

- Total radius: 10.7 metres,
- Height: 15 metres,
- Plasma radius: 6.2 metres,
- Plasma volume: 837 cubic metres,
- Magnetic field: 5.3 teslas,
- Maximum plasma flow: 15 megaamperes,
- Heating output: 73 megawatts,
- Fusion output: 500 megawatts,
- Medium temperature: 100 million degrees,
- Burning period: > 400 seconds.

J

JET

Joint European Torus; large-scale experiment for controlled nuclear fusion; Culham, England. In 1991, it was possible for the first time in the history of fusion research to release considerable energy by controlled nuclear fusion using the JET. For a period of two seconds, the facility generated a fusion power of 1.8 megawatt. In 1997 the JET generated fusion energy of 14 megajoules at a record fusion power of 13 megawatts with a fuel mixture consisting of equal parts of deuterium and tritium. An important measure of this success is also the ratio of fusion power output to heating input, which with 65 percent was more than twice the value achieved until that time.

Essential JET data:

- Large plasma radius 2.96 m,
- Small radii 1.25 m horizontal / 2.10 m vertical,
- Magnetic field 3.4 teslas,
- Plasma flow 3.2 - 4.8 megaamperes,
- Plasma heating 50 megawatts,
- Plasma temperature 250 million °C.

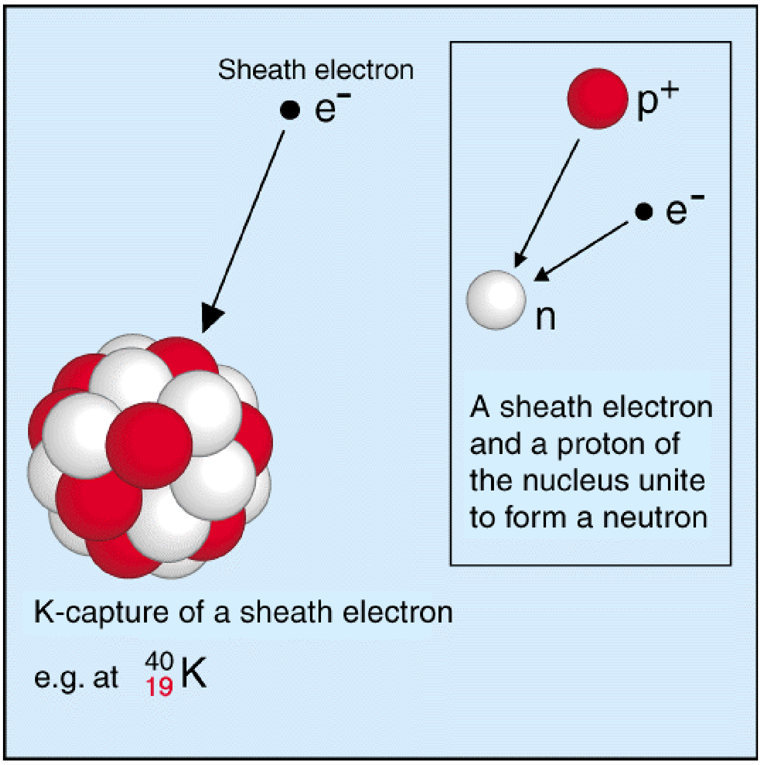
K

KBR

Nuclear power plant Brokdorf/Elbe, pressurized water reactor with an electric gross output of 1 440 MW, nuclear commissioning on 7th Oct. 1986.

K-capture

Capture of an orbiting electron from the nuclear shell by an atomic nucleus. →electron capture



K-capture, conversion of potassium-40 electron capture in argon-40

KERMA

Kinetic **E**nergy **R**eleased per Unit **Ma**ss. Kerma is a dose variable. Kerma K is the quotient of dE_{tr} and dm; whereby dE_{tr} is the sum of the starting values of kinetic energies of all charged particles released by indirectly ionizing radiation from the material in a volume element dV, and dm is the mass of the material in this volume element. All indications for a Kerma must mention the reference material (i.e. the material dm). The SI unit of the kerma is gray (Gy).

Kerntechnischer Hilfsdienst

The Kerntechnische Hilfsdienst GmbH in Eggenstein-Leopoldshafen is a company founded by the operators of nuclear facilities to combat damage in the case of accidents or incidents in nuclear facilities and during transport of radioactive substances. Qualified personnel and the required special auxiliary means are available to limit and eliminate the danger caused by the accidents or incidents.

Kerosene

Mixture of various hydrocarbon compounds, main component is dodecane; is used to dilute tributyl phosphate in the PUREX process for the reprocessing of nuclear fuel.

keV

Kiloelectron volt; 1 keV = 1 000 eV; →electron volt.

Key measurement point

Term from nuclear material monitoring. Place where nuclear material is present in a form enabling its measurement to determine the material flow or the inventory. Key measurement points record among others the input and output and the storage facilities in →material balance areas.

KFÜ

→nuclear reactor telemonitoring system

KGR

At the location of the Nuclear Power Plant Greifswald near Lubmin, five pressurized water reactors of Soviet design with an electric power of 440 MW each were in operation from 1973 to mid-1990:

- KGR-1: 3rd Dec. 1973 to 18th Dec. 1990, generated electrical energy: 41 TWh,
- KGR-2: 2nd Dec. 1974 to 14th Feb. 1990, generated electrical energy: 40 TWh,
- KGR-3: 6th Oct. 1977 to 8th Feb. 1990, generated electrical energy: 36 TWh,
- KGR-4: 22nd Jul. 1979 to 2nd Jun. 1990, generated electrical energy: 32 TWh,
- KGR-5: 26th Mar.1989 to 29th Nov. 1989, trial operation.

In 1990 three further units of the same power were in operation. Due to the safety deficit compared to western standards the reactors 1 to 5 were shut down in 1990 and the construction of the units 6 to 8 was suspended. The decommissioning work for the plant has started and shall be completed by 2012.

KHG

→Kerntechnische Hilfsdienst GmbH

Kilogram, effective

A special unit used for the application of safety measures regarding nuclear material. The quantity in effective kilograms corresponds:

- for plutonium to its weight in kilograms,
- for uranium with an enrichment of 1% and more to its weight in kilograms multiplied by the square of its enrichment,
- for uranium with an enrichment below 1% and more than 0.5% to its weight in kilograms multiplied by 0.0001,
- for depleted uranium (0.5% and below) and for thorium to its weight in kilograms multiplied by 0.00005.

KKB

Nuclear Power Plant Brunsbüttel/Elbe, boiling water reactor with an electric gross output of 806 MW, nuclear commissioning on 23r June 1976, final shutdown 21st July 2007. Lifetime electricity generation: 120.37 TWh.

KKE

Nuclear Power Plant Emsland in Lingen/Ems, pressurized water reactor with an electric gross output of 1 400 MW, nuclear commissioning on 14th April 1988.

KKG

Nuclear Power Plant Grafenrheinfeld/Main, pressurized water reactor with an electric gross output of 1 345 MW, nuclear commissioning on 9th December 1981.

KKI-1

Nuclear Power Plant Isar-1 in Essenbach/Isar, unit 1, boiling water reactor with an electric gross output of 912 MW, nuclear commissioning on 20th November 1977, final shutdown on 17th March 2011. Lifetime electricity generation: 197.4 TWh.

KKI-2

Nuclear Power Plant Isar-2 in Essenbach/Isar, unit 2, pressurized water reactor with an electric gross output of 1 485 MW, nuclear commissioning on 15th January 1988.

KKK

Nuclear Power Plant Krümmel/Elbe, boiling water reactor with an electric gross output of 1,402 MW, nuclear commissioning on 14th September 1983, final shutdown on 4th July 2009. Lifetime electricity generation: 201.7 TWh.

KKN

Nuclear Power Plant Niederaichbach/Isar, CO_2-cooled, D_2O-moderated pressure tube reactor with an electric gross output of 106 MW, nuclear commissioning on 17th December 1972. The plant was shut down a short time later for economic reasons resulting from the fast and successful development and introduction of the pressurized and boiling water reactor lines. The plant was initially transferred into safe enclosure. On 6th June 1986, the licence for the total elimination was granted. On 17th August 1995, all disassembly work was completed and thus the „green meadow“ condition restored for the first nuclear power plant in Germany.

KKP-1

Nuclear Power Plant Philippsburg/Rhine, unit 1, boiling water reactor with an electric gross output of 926 MW, nuclear commissioning on 9th March 1979, final shutdown on 17th March 2011. Lifetime electricity generation: 186.8 TWh.

KKP-2

Nuclear Power Plant Philippsburg/Rhine, unit 2, pressurized water reactor with an electric gross output of 1 458 MW, nuclear commissioning on 13th December 1984.

KKR

Nuclear Power Plant Rheinsberg, pressurized water reactor with an electric gross output of 70 MW, was commissioned as the first nuclear power plant of the former GDR on 6th May 1966 and finally shut down on 1st June 1990. The total gross output amounted to 9 TWh. The disassembly work has commenced and is to be completed with the „green meadow“ condition.

KKS

Nuclear Power Plant Stade/Elbe, pressurized water reactor with an electric gross output of 672 MW, nuclear commissioning on 8th January 1972. Final shut down on 14th November 2003.

KKU

Nuclear Power Plant Unterweser in Rodenkirchen-Stadland/Weser, pressurized water reactor with an electric gross output of 1 410 MW, nuclear commissioning on 16th September 1978, final shutdown on 18th March 2011, application for decommissioning on 4th May 2012, lifetime electricity generation: 289.75 TWh.

KKW-Nord

→KGR

K-meson

Elementary particle of the meson group. →elementary particle

KMK

Nuclear Power Plant Mülheim-Kärlich/Rhine, pressurized water reactor with an electric gross output of 1 308 MW, nuclear commissioning on 1st March 1986; since 1988 out of operation due to the proceedings on the validity of the 1st partial permit. License for decommissioning applied.

KNK-II

Compact sodium-cooled nuclear reactor plant in the Research Centre Karlsruhe, fast sodium-cooled reactor with an electric gross output of 21 MW. The reactor was put into operation as a thermal reactor under the name KNK-I. Following the conversion to a fast reactor, it was operated under the name KNK-II from 10th Oct. 1977 onwards. On 23rd Aug. 1991 it was definitely shut down. The decommissioning work commenced in 1993 and is to be completed with the „green meadow“ condition.

Konrad

Iron pit in Salzgitter shut down in 1976 and intended as a repository for radioactive waste with negligible heat generation and for large-scale components from nuclear facilities. On 31st Aug. 1982, application for initiation of the procedure for official approval of the plan for ultimate waste disposal was filed. On June 5, 2002, the licence for the emplacement of a waste package volume of 300.000 m^3 of radioactive waste with negligible heat generation was issued. After final court decisions in 2007 the former mine will be converted into a repository to be ready for waste storage in 2019.

K-radiation

K-radiation is the characteristic X-radiation emitted during the refilling of a K-shell, e.g. after →K-capture. The refilling of an inner shell can also occur without radiation; the released energy is then transferred to an electron on a shell further outward leaving the atomic sheath (Auger effect).

KRB-A

Nuclear power plant RWE-Bayernwerk in Gundremmingen/Danube, boiling water reactor with an electric gross output of 250 MW, nuclear commissioning on 14th August 1966, final shutdown in January 1977; cumulative power generation 15 TWh. Decommissioning was approved on 26th May 1983.

KRB-B

Nuclear Power Plant Gundremmingen/Danube, unit B, boiling water reactor with an electric gross output of 1 344 MW, nuclear commissioning on 9th March 1984.

KRB-C

Nuclear Power Plant Gundremmingen/Danube, unit C, boiling water reactor with an electric gross output of 1 344 MW, nuclear commissioning on 26th October 1984.

KTA

Kerntechnischer Ausschuss; Nuclear Standards Committee. The KTA has the task of preparing safety-related rules and promoting their application in fields of nuclear technology where a uniform opinion of specialists, manufacturers, builders and operators of nuclear facilities, experts and authorities has formed.

KTG

Kerntechnische Gesellschaft; Nuclear Society, Robert-Koch-Platz 4, 10115 Berlin. The Kerntechnische Gesellschaft e. V. is a non-profit-making association made up of scientists, engineers, technicians and other persons with the aim of promoting science and technology in the field of peaceful use of nuclear energy and related disciplines.

KWG

Nuclear Power Plant Grohnde/Weser, pressurized water reactor with an electric gross output of 1 430 MW, nuclear commissioning on 1st September 1984.

KWL

Nuclear Power Plant Lingen/Ems, boiling water reactor with fossil superheater with an electric gross output of 240 MW (82 MW of which from the fossil superheater). Nuclear commissioning on 31st January 1968; final shutdown on 5th January 1977; cumulative power generation: 11 TWh. Decommissioning was approved on 21st November 1985. Since 30th March 1988 the plant is in the „safe enclosure“ condition which, according to the approval, continues for 25 years.

KWO

Nuclear Power Plant Obrigheim/Neckar, pressurized water reactor with an electric gross output of 357 MW. Nuclear commissioning took place on 22nd September 1968. Final shutdown after 37 years of operation on 11.05.2005. Total electricity production 86 TWh.

KWW

Nuclear Power Plant Würgassen/Weser, boiling water reactor with fossil superheater with an electric gross output of 670 MW, nuclear commissioning on 20th October 1971. The plant was shut down after an operating period of 128 333 h and a cumulative output of about 73 TWh on 26th August 1994 and decommissioning preparations have commenced.

L

Large-scale research facilities

15 German large-scale research facilities joined to form the →Hermann von Helmholtz Association of National Research Centres (HGF - „Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren").

LAW

Low active waste; usually with an activity concentration of less than 10^{10} Bq/m^3.

LD_{50}

→lethal dose

Leach rate

Measure for the leaching behaviour of solids in liquids. For instance the following is valid for solidified radioactive waste in boiling distilled water:

Cemented waste 10^{-2} to 10^{-3} g/cm² · day,

Vitrified waste 10^{-5} to 10^{-7} g/cm² · day.

Lepton

„Light" →elementary particle. Leptons include elementary particles which are subject only to low and electromagnetic interaction: neutrinos, the electron, the myon and the τ-particle.

LET

→linear energy transfer

Lethal dose

Ionizing radiation dose leading to the death of the irradiated individual due to acute radiation injuries. The average lethal dose (LD_{50}) is the dose where half of the individuals with similar irradiation quantities die. LD_1 is the dose leading to a mortality of 1% of the irradiated persons; consequently, LD_{99} is lethal for all (99%) persons irradiated. Taking account of an increased radiation sensitivity of certain population groups on the one hand and the progress of medical care on the other hand, mainly homogeneous irradiation of the whole human body - the bone marrow dose is particularly important in this case - an LD_1 of 2.5 Gy, LD_{50} of 5 Gy and LD_{99} of 8 Gy results.

Liability convention

→Convention on Third Party Liability in the Field of Nuclear Energy

Liability for nuclear facilities

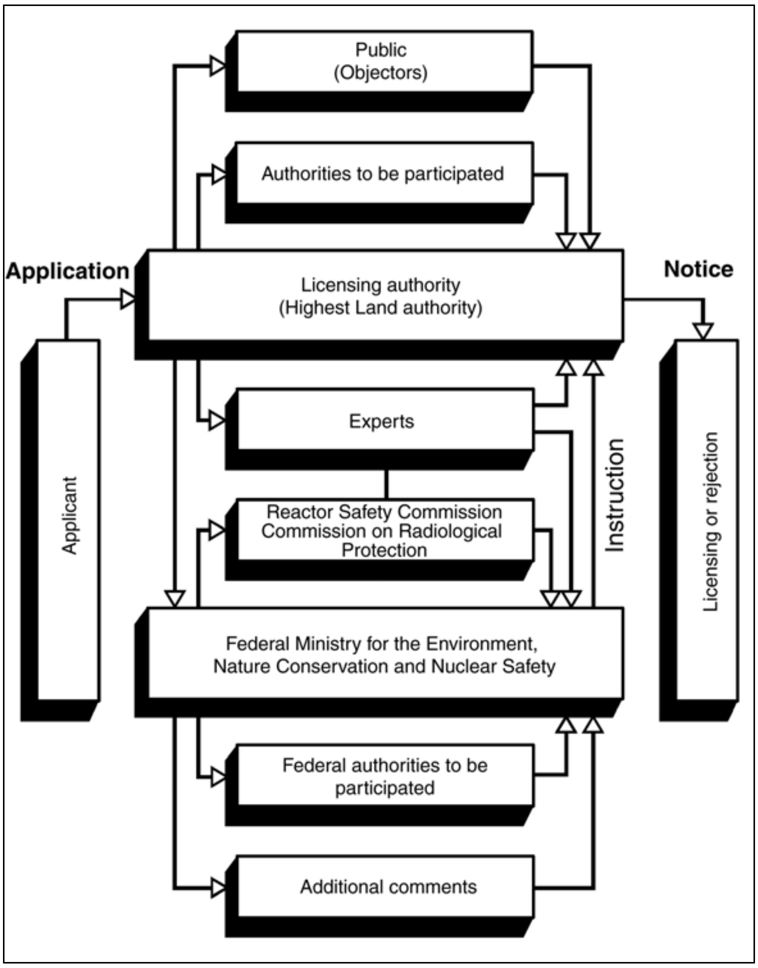
Pursuant to the Atomic Energy Act, owners of nuclear facilities are subject to financially unlimited liability for personal injuries and property damage; irrespective of whether the injury or damage was caused by culpable action or not. The owner of the facility must furnish proof of the required financial security to meet the legal liability for damages. For nuclear power plants, the financial security amounts to Euro 2,500 million per claim. The financial security can be provided by a liability insurance or an indemnity or warranty obligation by a third party.

Licensing procedure

The license for the construction and operation of a nuclear facility is to be applied for in writing before the licensing authority of the Federal State in the Federal Republic of Germany where the facility is to be erected. The documents required to examine the licensing prerequisites, in particular a safety report allowing third parties to evaluate whether their rights might be affected by the effects resulting from the facility and its operation must be included with the application. The safety report shows the fundamental design features, the safety-related design principles and the function of the facility including its operating and safety systems. If the documents required for the design are complete, the licensing authority is required to announce the project in its official gazette and in addition in the local papers published in the region of the facility site. During a two-month period, the application, safety report and a brief description of the facility are to be made available for public inspection at the licensing authority and at the site of the project. Objections may be raised in writing at the licensing authority during the term for public inspection. Upon expiry of the term of public inspection, all objections that are not based on special private titles are excluded. The licensing authority is required to verbally discuss the objections with the applicant and the persons raising the objections. The discussion date is used to discuss the objections as far as this is important for the examination of the licensing prerequisites. The discussion date provides the opportunity for the persons raising objections to explain their objections. In examining the application the authority is assisted by independent experts. As a rule, these are the Technical Inspection Agencies, the Company for Industrial Plants and Nuclear Safety and other institutions such as the German Meteorological Service and experts from university institutes and research facilities. Upon receipt of a licensing application, the licensing authority of a Federal State informs the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. This ministry supervises the licensing activity of the Federal state authority, requests necessary documents and obtains, if necessary, further opinions. The Reactor Safety Commission and the Commission on Radiological Protection assist the ministry as consultants. The competent Federal state authority takes a decision assessing the overall result of the procedure. The license may be granted only if

- there are no facts giving rise to reservations about the reliability of the applicant and the persons responsible for the erection, management and supervision of the operation of the facility and whether the persons responsible for the erection, management and supervision of the operation of the facility have the required expert knowledge for this purpose,
- the required precautions against damage resulting from the erection and the operation of the facilities have been taken in compliance with current scientific knowledge and state-of-the-art technology,
- the required financial security has been undertaken to meet legal liability for damages,
- the required protection against fault measures or other third party influences is ensured,
- essentially public interests, in particular regarding the cleanliness of water, air and ground, do not oppose the chosen site of the facility.

The persons concerned may appeal against the licenses granted before the Administrative Courts.



Course of a licensing procedure for nuclear facilities (Germany)

Life time, mean

A period of time also called short life during which the number of radionuclide nuclei reduces to 1/e (e = 2.718..., base of natural logarithms). The life is equal to the reciprocal of the →decay constant λ. Life and →half-life T are related as follows:

$\tau = T/\ln 2 \approx 1.44 \cdot T$.

Light water reactor

Collective term for all H_2O moderated and cooled reactors; →boiling water reactor, →pressurized water reactor (H_2O = "light" water, in contrast to D_2O = "heavy" water). The light water reactor produces heat by controlled nuclear fission. The reactor core consisting of fuel and control elements is enclosed by a water-filled steel pressure vessel. The heat generated by the fission heats the water which evaporates in the pressure vessel in a light water reactor; in the pressurized water reactor, the steam evaporates in a steam generator of a secondary circuit. The steam energy is converted into rotary motion of the turbine to which a generator for the generation of electricity is connected. After flowing through the turbine, the steam condenses into water in the condenser and is recirculated to the pressure vessel or steam generator. The water required to cool the condenser is taken from a river and refed into the river in warmed condition or the heat is dissipated via a cooling tower into the atmosphere.

Linac

Acronym for →linear accelerator.

Line losses

Energy losses caused by the transport of the energy carriers to the consumption locations.

Linear accelerator

A long straight tube in which particles (mostly electrons or protons) are accelerated by electrostatic fields or electromagnetic waves and thus achieve very high energies (Stanford 2-miles Linac: 40 GeV electrons).

Linear amplifier

Pulse amplifier with an output amplitude proportional to the input pulse amplitude.

Linear energy transfer

Term in dosimetry of ionizing rays; energy transfer of an ionizing particle to the matter penetrated by radiation. The linear energy transfer is equal to the energy d*E* which a charged particle loses at a distance dl.

$$L_{\infty} = \frac{dE}{dl}$$

The linear energy transfer is indicated in keV/µm. The following relation has been fixed between the →quality factor Q (L) and the unlimited linear energy transfer L_{∞}:

Unlimited linear energy transfer L_{∞} in water, (keV μm^{-1})	*Q* (L)
<10	1
10 - 100	0.32 *L* - 2.2
>100	300 / √*L*

Relation between the linear energy transfer and the quality factor

Linear heat generation rate

Measurement of the volume of achievable heat per linear unit of the fuel rod. It is indicated in W/cm rod length (e. g. Biblis-A: 563 W/cm).

Liquid scintillation counter

Scintillation counter in which the scintillator is an organic liquid (e.g. diphenyl oxazole, dissolved in toluene). Preferred detection and measuring device for the low-energetic beta radiation of tritium and carbon -14.

LMFBR

Liquid Metal Fast Breeder Reactor cooled with liquid metal.

Load ranges of power plants

The mains load resulting from the power requirements of the consumers must be covered by power plant operation adjusted in terms of time. Base load, intermediate load and peak load are distinguished in this context. The power plants are used in these ranges according to their operational and economic properties. Run-of-river, lignite-fired and nuclear power plants run base load, coal-fired and gas-fired power plants run intermediate load, and storage and pumped storage power plants as well as gas turbine facilities cover peak loads. Optimum operation is ensured under today's and future circumstances if the ratio of the power plant output in the base load on the one hand and in the intermediate and peak load on the other hand is 1:1.

LOCA

Loss-of-Coolant Accident.

Local dose

Dose equivalent for soft tissue measured at a certain point. The local dose in the case of penetrating radiation is the →ambient dose equivalent H*(10), local dose for radiation with low penetration depth is the →directional dose equivalent H'(0.07, Ω). The local dose in the case of penetrating radiation is an estimated value for the effective dose and the organ doses of deep organs for radiation with low penetration depth is an estimated value for the skin dose of a person at the place of measurement.

Long-lived radionuclides

The Radiation Protection Ordinance defines radioactive substances with a half-live of more than 100 days as long-lived radionuclides.

Long-time dispersion factor

Calculation factor in the dispersion calculation for the emission of pollutants into the atmosphere taking account of the horizontal and vertical dispersion of the pollutant cloud as well as the effective emission height (stack height and thermal amplified region). The long-time dispersion factor is replaced by the short-time dispersion factor in the dispersion calculation if the emission does not last more than an hour.

Loop

Closed tube circuit which can accommodate materials and individual parts for testing under various conditions. If part of the loop and its contents is located within the reactor, it is called an in-pile-loop.

Lost concrete shielding

Ultimate waste package for medium active waste are provided with a sheathing layer of cement mortar for radiation shielding. This shielding is practically connected permanently to the waste package and is also stored in the repository. It is therefore considered „lost“.

Lost energy

The quantity of energy lost during conversion, transport and final consumption for utilization.

Low-temperature rectification

Process to segregate gases by liquefying a gas mixture at very low temperatures (approx. minus 120 to minus 200 °C) and subsequent separation taking advantage of the different boiling points (rectification).

LSC

Liquid scintillation counter. Radiation measuring device preferably used to measure radionuclide emitting low-energetic beta radiation such as tritium, carbon-14.

LWR

→light water reactor

M

Magnetic lens

Magnetic field arrangement exercising a focussing or defocusing effect on a ray of charged particles.

Magnox

Cladding tube material in graphite-moderated, gas-cooled reactors. Magnox (**mag**nesium **n**on **ox**idizing) is an alloy of Al, Be, Ca and Mg.

Magnox reactor

Graphite-moderated, CO_2-cooled reactor type with natural uranium fuel elements covered by a magnox sheath. Reactor type mainly built in Great Britain; e.g. Calder Hall, Chapelcross, Wylfa.

Maintenance

Maintenance and repair measures for apparatuses, machines and plant components. Maintenance can be preventive as a routine measure or be carried out after occurrence of a technical failure of a plant component.

MAK

Threshold limit value. This value is the highest permissible concentration of a working material as a gas, steam or suspended matter in the air at the working place. According to the present state of knowledge, this concentration generally does not affect the health of the workers or cause undue nuisance even with repeated and long-term, as a rule eight-hour daily effect when observing average weekly working hours. Apart from practical circumstances of the working processes, the fixing of threshold limit values above all takes effect characteristics of the material concerned into account. The decisive elements are scientifically sound criteria for health protection and not the technical and economic implementation possibilities in practice.

Manipulator

Mechanical and electromechanical devices for the safe remote-controlled handling of radioactive substances.

Marking

Identification of a substance by adding mostly radioactive atoms which can be easily traced in the course of chemical or biological processes. →tracer

Mass, critical

→critical mass

Mass defect

Mass defect describes the fact that the nuclei made up of protons and neutrons have a smaller rest mass than the sum of the rest masses of the protons and neutrons forming the nucleus. The mass difference is equal to the released →binding energy. For the alpha particle with a mass of 4.00151 atomic mass units, the structure of two protons (1.00728 atomic mass units each) and two neutrons (1.00866 atomic mass units each), a mass defect of 0.03037 atomic mass units results. This corresponds to an energy (binding energy) of about 28 MeV.

Mass number

Mass of an atom in nuclear mass units. Number of protons and neutrons - the nucleons - in an atomic nucleus. The mass number of U-238 is 238 (92 protons and 146 neutrons).

Mass spectrograph, mass spectrometer

Devices for isotope analyses and determination of isotope mass by the electric and magnetic separation of an ion ray.

Material balance area

Term of nuclear material monitoring describing a space where the nuclear material quantity in the case of every transfer and the inventory of nuclear material in every material balance area can be determined with fixed procedures so that material balance can be established.

Material, depleted

Material with a concentration of an isotope or several isotopes of a component below its natural value.

Material, enriched

Material with a concentration of an isotope or several isotopes of a component above its natural value.

Material, unaccounted for

Term of nuclear material monitoring. Difference between real inventory and the stock of nuclear material in the account books. →MUF

MAW

Medium active waste; usually with an activity concentration of 10^{10} to 10^{14} Bq/m^3.

Max Planck Institute for Plasma Physics

The Max-Planck-Institut für Plasmaphysik (IPP) is concerned with investigating the physical fundamentals underlying a fusion power plant which - like the sun - is designed to gain energy from the fusion of light atomic nuclei. The two concepts for the magnetic confinement of fusion plasma - →Tokamak arrangement and →stellarator principle - are examined for their power plant suitability at the IPP. In Garching, the ASDEX-Upgrade Tokamak and the WENDELSTEIN 7-AS stellarator are operated. The successor WENDELSTEIN 7-X is under preparation at the branch institute of IPP in Greifswald. The work of the IPP is integrated in national and European programmes as well as in world-wide co-operation. On the European level, the IPP presently involved in the largest fusion experiment in the world →JET (Joint European Torus). At the same time, IPP co-operates in the world-wide project for the International Thermonuclear Experimental Reactor →ITER.

Maximum capacity

The maximum capacity of a power plant limited by the weakest plant section in terms of power. Depending on the period of time during which the maximum power can be operated, a distinction is drawn between a maximum capacity of one-hour or of 15 hours and more. The net maximum power of all power plants of general supply in Germany amounted to a total of 101 400 MW in November 1999.

Maximum credible accident

→MCA

MBA

→material balance area

MCA

Maximum **c**redible **a**ccident. Term from reactor safety, now replaced by the more comprehensive term of design basis accident.

µCi

Microcurie, symbol: µCi; one millionth curie. →curie

MCI

Millicurie, symbol: mCi; one thousandth curie. →curie

Mechanical-draft cooling tower

Cooling tower with ventilator to remove the cooling air. Compared to the →natural-draft cooling tower, the mechanical-draft cooling tower has an advantageous lower height but higher operating costs. →closed-circuit cooling

Megawatt

Million times the power unit of watt (W), symbol: MW. 1 MW = 1000 kW = 1 000 000 W.

Meson

Originally, name for elementary particles with a mass between the myon mass and the nucleon mass. The group of mesons now include the elementary particles which, like the →baryons are subject to both strong and weak and electromagnetic interaction, but in contrast to the baryons, with a spin equal to zero. For example pions and K-mesons belong to the mesons. →elementary particles

MeV

Megaelectron volt, 1 000 000 eV.

Microcurie

1 Microcurie (µCi) = 1/1 000 000 Ci. →curie

Millicurie

1 millicurie (mCi)= 1/1 000 Ci. →curie

Millirem

1 millirem (mrem) = 1/1 000 rem = 0.01 millisievert (mSv). →rem

30-millirem concept

The radiation exposure of the human being due to the discharge of radioactive substances into the air or water during the operation of nuclear facilities and while handling radioactive substances is governed by the Radiation Protection Ordinance by means of strictly limiting values. The Section of the Radiation Protection

Ordinance governing the protection of the population specifies the following dose limit values resulting from radioactive substance disposal in air or water:

effective dose 0.3 mSv/year,
gonads, uterus,
red bone marrow 0.3 mSv/ year,
all other organs 0.9 mSv/ year,
bone surface, skin 1.8 mSv/ year.

This radiation protection concept is named after the former dose unit millirem - 0.3 mSv is equal to 30 millirem.

Mixed oxide

Oxidic nuclear fuel from a mixture of uranium and plutonium (MOX).

Mixer settler

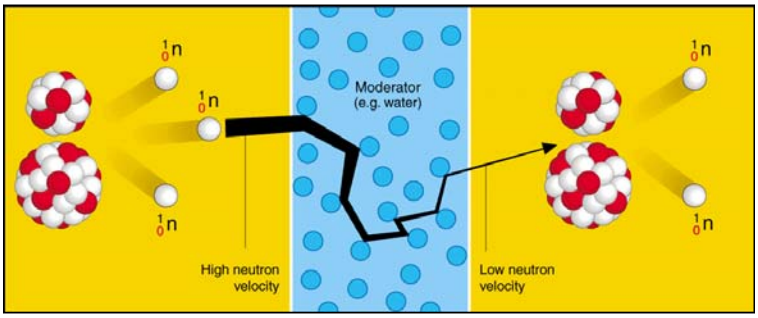
Extraction apparatus. Two liquids of different weight which cannot be mixed with one another (e.g. aqueous and organic phase) are mixed using stirrers, whereby certain chemical compounds pass from one liquid phase into the other. The two liquids subsequently settle due to natural gravity.

Moderation

Process during which the kinetic energy of the neutrons is reduced by impacts without perceptible absorption losses. The energy-rich neutrons generated in nuclear fission with energies around 1 MeV are reduced to lower energies in the energy range of →thermal neutrons (0.025 eV), since they probably initiate new fissions in this energy range.

Moderator

Material used to „decelerate“ fast neutrons to low energies, since the fission of the U-235 nuclei results in a better yield at low neutron energies. Among others, light water, heavy water and graphite are used as moderators.



Model representation of the moderator effect

Molecule

An atomic group held together by chemical forces. The atoms of a molecule may be identical (H_2, N_2, S_2) or different (H_2O, CO_2).

Monazite

Yellow to reddish-brown mineral. Monazite is cerium phosphate; it often contains additional noble earths such as thorium.

Monitor

Device to monitor ionizing radiation or the activity concentration of radioactive substances (e.g. in the air or water) signalling a warning when certain adjustable limit values are exceeded. A monitor is also used for quantitative measurements.

Monitoring area

A monitoring area is a radiation protection area for which fixed dose limit values are valid and which is subject to monitoring according to stipulated regulations. In adaptation to the Euratom basic standards, a monitoring area is a radiation protection area that does not belong to the controlled area and in which persons in a calendar year may receive an effective dose of more than 1 millisievert or higher organ doses than 15 millisievert for the eye lens or 50 millisievert for the skin, hands, forearms, feet and ankles.

Monte-Carlo Method

Statistical calculation procedure, e.g. to calculate the neutron flux distribution in burnup and shielding calculations. In this context, the history of individual, statistically selected neutrons is calculated until sufficient individual evolutions (individual destinies) again result in numerical average values for the neutron flux at the points considered. The calculation, which is simple in itself, requires numerous calculations, since a high degree of accuracy is achieved only with a large number of individual destiny calculations.

MOX

→mixed oxide

mrem

millirem, 1/1 000 rem. →rem

MTR

Materials Testing Reactor with high neutron flux density.

MUF

material **u**naccounted **f**or. Term of nuclear material monitoring. Difference between real inventory and the stock of nuclear material in the account books.

Mülheim-Kärlich

Nuclear Power Plant Mülheim-Kärlich/Rhine, pressurized water reactor with an electric gross output of 1 308 MW, nuclear commissioning on 1st March 1986; out of operation since 1988 due to the proceedings concerning the validity of the 1st partial permit. Decommissioning in progress.

Multiple disaggregation

→spallation

Multiple-channel analyser

Pulse amplitude analyser sorting the pulses of energy-proportional detectors according to the amplitude and thus the radiation energy and recording them in the corresponding channel. Multiple-channel analysers have more than 8 000 channels.

Multiplication factor

Ratio of neutron number in a neutron generation to the neutron number in the generation immediately preceding that generation. →Criticality of a reactor occurs when this ratio is equal.

MW

Megawatt, million times the power unit of watt (W). 1 MW = 1 000 kW = 1 000 000 W.

MWd

Megawatt day; 1 MWd = 24 000 kWh. In the case of the complete fission of 1 g U-235, about 1 MWd energy is released.

MWd/t

Megawatt day per tonne; unit for the thermal energy output for one tonne of nuclear fuel during the service time in the reactor. →burnup

MWe

Megawatt electric; electric output of a power plant in megawatt. The electric output of a power plant is equal to the thermal overall power multiplied by the efficiency of the plant. The power plant efficiency of light water reactors amounts to 33 to 35% compared to up to 40% for modern coal-, oil- or gas-fired power plants.

MWth

Megawatt thermal; overall power of a nuclear reactor in megawatt. →MWe

Myon

Electrically charged instable →elementary particle with a rest energy of 105.658 MeV corresponding to 206.786 times the rest energy of an electron. The myon has an average half-life of $2.2 \cdot 10^{-6}$ s. The myon belongs to the elementary particle group of the leptons.

MZFR

Multipurpose research reactor in the Research Centre, pressurized water reactor (moderated and cooled with D_2O) with an electric gross output of 58 MW, nuclear commissioning on 29th September 1965; on 3rd May 1984 it was finally shut down; cumulative power generation: 5 TWh. The decommissioning work commenced in 1995 and is to be completed with the „green meadow“ condition.

N

Natural draught cooling tower

→Wet cooling tower or →dry cooling tower utilizing the natural draught (stack effect) of the cooling tower to remove the cooling air. Natural draught wet cooling towers for a cooling power of some thousand MW are about 150 m high and 120 m in diameter at the base.

Natural uranium

Uranium in the isotope composition occurring in nature, Natural uranium is a mixture of uranium-238 (99.2739%), uranium-235 (0.7205%) and a very low percentage of uranium-234 (0.0056%).

nCi

Nanocurie, symbol: nCi; one billionth curie. →curie

NEA

Nuclear Energy Agency of the OECD.

Neutrino

Group of electrically neutral →elementary particles with a mass of almost zero.

Neutron

→Uncharged elementary particle with a mass of $1.67492716 \cdot 10^{-27}$ kg and thus a slightly greater mass than that of the proton. The free neutron is instable and decays with a half-life of 11.5 minutes.

Neutron activation analysis

→activation analysis

Neutron density

Number of free neutrons in a volume element divided by this volume element.

Neutron, fast

Neutron with a kinetic energy of more than 0.1 MeV.

Neutron flux density

Product of neutron density and neutron velocity integrated over all directions of particle movement. Unit: $cm^{-2} \cdot s^{-1}$.

Neutron, intermediate

Neutron with an energy beyond that of a slow neutron, however lower than that of a fast neutron; generally within the range of 10 and 100 000 eV.

Neutron, slow

Neutron, the kinetic energy of which falls below a certain value - frequently 10 eV is selected. →neutrons, thermal

Neutron source

Facility to generate free neutrons.

Neutrons, delayed

Neutrons not generated directly during the nuclear fission, but delayed as a consequence of a radioactive conversion of fission products. Less than 1% of the neutrons involved in nuclear fission are delayed. →neutrons, prompt

Neutrons, epithermal

Neutrons the kinetic energy distribution of which exceeds that of the thermal movement. →neutrons, thermal

Neutrons, prompt

Neutron emitted immediately during nuclear fission (within about 10^{-14} s); in contrast to delayed neutrons which are sent out seconds to minutes after the fission of fission products. Prompt neutrons make up more than 99% of the neutrons.

Neutrons, thermal

Neutrons in thermal equilibrium with the ambient medium. Thermal neutrons most probably have a neutron velocity of 2200 m/s at 293.6 K corresponding to an energy of 0.0253 eV. Fast neutrons as generated during nuclear fission are decelerated by collisions with the atoms of the moderator material (usually water, heavy water or graphite) to thermal energy, they are 'thermalized'.

Non-destructive testing

Testing for hidden defects in material using methods which do not damage or destroy the test pieces. Frequently x-rays, gamma radiation or ultrasound are used.

Non-energetic consumption

The quantities of hydrocarbons gained from oil, coal, gas not used for energy generation - heat among others - but for products, mostly synthetics and chemicals.

Non-proliferation Treaty

The aim of the international Treaty on the Non-proliferation of Nuclear Weapons and the resulting nuclear material monitoring is the timely detection of nuclear material diversion for the manufacture of nuclear weapons or deterrence of such deviation through the risk of detection. Corresponding monitoring in Germany is performed by Euratom and the International Atomic Energy Agency.

Normal operation and anticipated operational occurrences

Operation of a facility in compliance with its design approved by the competent authority comprising:

- Normal operation: operations for which the facility is designed and suitable while in an operable state.
- Abnormal condition: operations which run in the event of malfunctions of plant parts or systems provided safety reasons do not preclude the continuation of operations.
- Maintenance procedures.

NPP

Nuclear power plant

NPT

→Non-proliferation Treaty

NRC

Nuclear Regulatory Commission, Rockville, Maryland; licensing and regulatory authority for nuclear facilities in the USA.

NSSS

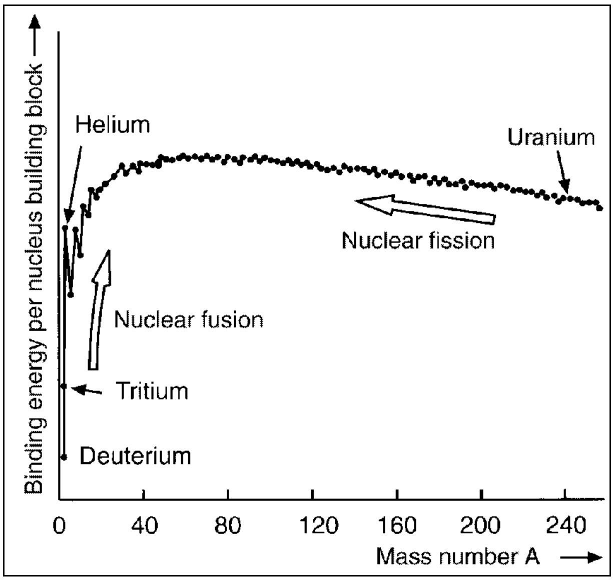
Nuclear steam supply system; nuclear steam generator system.

Nuclear chemistry

Branch of chemistry dealing with the study of nuclei of atoms and nuclear reactions applying chemical methods. →radio chemistry

Nuclear energy

Inner binding energy of atomic nuclei. The nuclear building blocks show various degrees of mutual binding from one atom type to another. The maximum binding energy per nuclear building block is within the range of the mass number 60. By means of nucleus conversion, energy can therefore be obtained either by fission of heavy nuclei such as uranium or by fusion of lighter nuclei such as hydrogen. The fission of 1 kg U-235 supplies about 23 million kWh, during the fusion of deuterium and tritium (DT-reaction) to 1 kg helium, energy of about 120 million kWh is released. In contrast, the combustion of 1 kg coal supplies only about 10 kWh. →fusion, →nuclear fission



Nuclear binding energy depending on the mass number of the nucleus of the atom

Nuclear event

In accordance with the definition of the Atomic Energy Act, any event causing damage when the event or damage is due to the radioactive properties or a connection of radioactive properties with toxic, explosive or other hazardous properties of nuclear fuels or radioactive products or waste, or to ionizing radiation emitted from another radiation source within the nuclear plant.

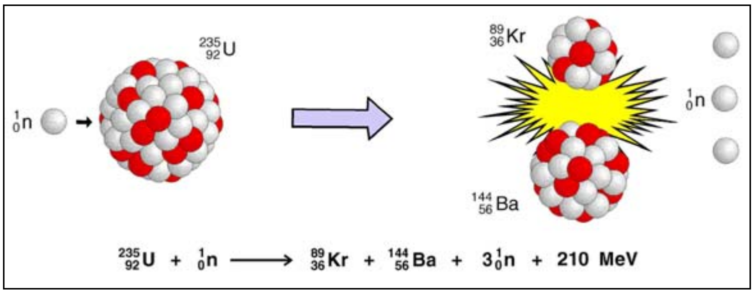
Nuclear facility

For the application of liability regulations, the Atomic Energy Act defines a nuclear plant as follows:

- Reactors, except for those which are part of a means of transport;
- Factories for the generation or treatment of nuclear material,
- Factories for the separation of isotopes in nuclear fuel,
- Factories for the reprocessing of irradiated nuclear fuel;
- Facilities for the storage of nuclear materials, except for such materials during transport.

Nuclear fission

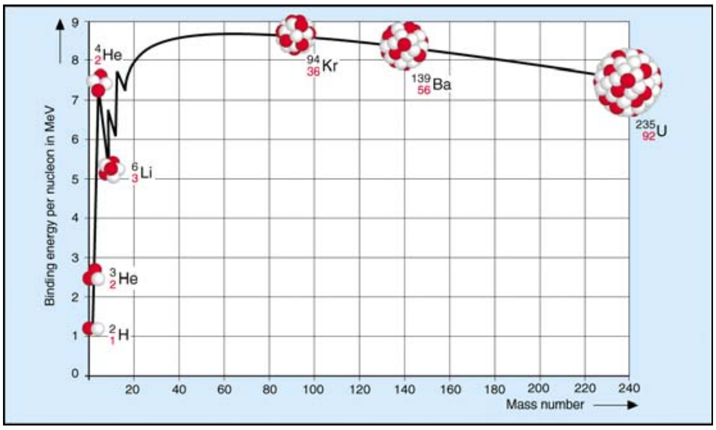
Fission of an atomic nucleus into two parts of the same size caused by the collision of a particle. Nuclear fission may also occur spontaneously in the case of very heavy nuclei; →fission, spontaneous. The capture of a neutron induces fission of the nucleus of uranium-235. During the fission, in general two - more rarely three - →fission products, two to three neutrons and energy are generated.



Example for nuclear fission of U-235

In the uranium nucleus the →nucleons are bound with an average energy of about 7.6 MeV per nucleon. In the fission product nuclei, the medium binding energy per nucleon amounts to approx. 8.5 MeV. This difference in binding energy of 0.9 MeV per nucleon is released in the nuclear fission. Since the uranium nucleus has 235 nucleons, a quantity of energy of about 210 MeV is released per fission. It is made up of the following partial amounts:

- kinetic energy of fission products 175 MeV,
- kinetic energy of fission neutrons 5 MeV,
- energy of the γ-radiation occurring during the fission 7 MeV,
- energy of β/γ -radiation during the decay of the radioactive fission products 13 MeV,
- energy of the neutrinos 10 MeV.



Course of nuclear binding energy

Due to the neutrons released during the nuclear fission a →chain reaction is possible in principle. Facilities where fission chain reactions are initiated in a controlled manner are called nuclear reactors.

Nuclear fuel

In accordance with the definition of the Atomic Energy Act, nuclear fuel consists of special fissile substances in the form of

- plutonium-239 and plutonium-241,
- with the isotopes 235 or 233 enriched uranium,
- substances containing one or several of the aforementioned substances,
- substances with the aid of which a self-perpetuating chain reaction can be upheld in a suitable plant (reactor) and which are determined in an ordinance having the force of law.

Nuclear fuel cycle

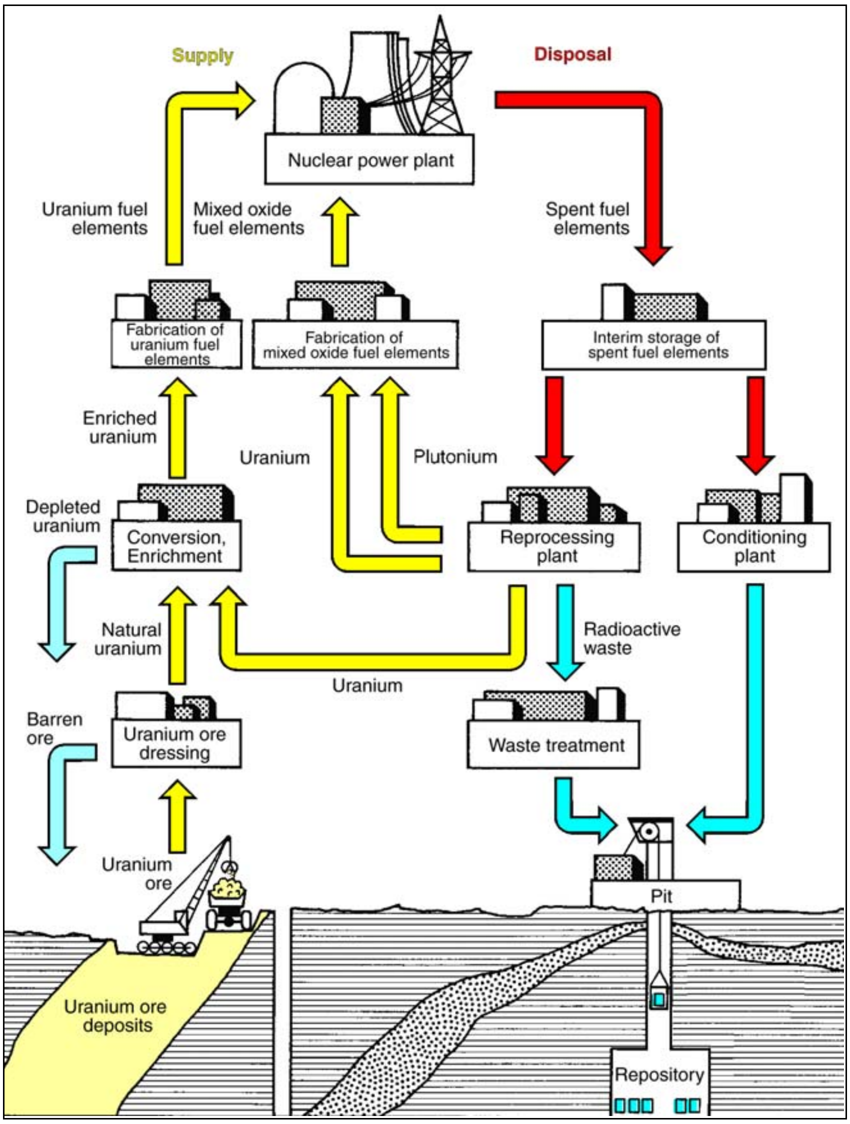
A number of process stages in the supply and waste management of nuclear fuel for reactors.

- Supply:

The point of departure of nuclear energy utilization is the supply of nuclear reactors with uranium. The uranium contents of mined ores amount typically to 0.2%. The uranium is concentrated in a treatment process. The commercial article „Yellow Cake" results, which contains about 70 to 75% uranium. The uranium contained in the Yellow Cake has a natural isotope composition of 0.7% U-235 and 99.3% U-238. Nuclear power plants need uranium with a proportion of 3 to 5% of the fissile isotope U-235. Therefore, the uranium must be enriched to U-235. For this purpose the uranium is converted into the chemical compound UF_6, which can easily be transferred to the gas phase, since enrichment is only easily possible in the gas phase. Enrichment processes (→gas centrifuge or →diffusion separation processes) use the low mass difference of the U-235 and U-238 molecules of UF_6 to separate these two components. The product of the enrichment plant is UF_6 with a U-235 share of approx. 3 to 5%. In the fuel element factory, the UF_6 is converted into UO_2. The UO_2 powder is used to press pellets which are sintered at temperatures of more than 1700 °C, filled into seamlessly drawn cladding tubes made of a zircon alloy and sealed gas-tight. Thus, individual fuel rods are obtained which are grouped into fuel elements. The fuel elements of a pressurized water reactor contain about 340 kg uranium, those of a boiling water reactor about 190 kg uranium.

- Waste management:

The service period of fuel elements in the reactor is three to four years. Nuclear energy is converted to electricity by nuclear fission. During this process the percentage of fissile U-235 decreases, and the partly radioactive fission products and considerable quantities of the new, partly fissile nuclear fuel plutonium are generated. All activities relating to treatment, reprocessing and disposal of fuel elements are summarized under the term waste management. Two types of disposal are possible: →reprocessing by recovery and reuse of the usable plutonium and uranium portions or direct ultimate waste disposal where the spent fuel elements are disposed of altogether as waste. The fuel elements are stored initially in an interim storage facility where the activity decreases. During the following reprocessing, reusable uranium and plutonium are separated from the radioactive fission products. For reuse in the nuclear power plant plutonium and uranium - possibly after enrichment - must be processed into fuel elements. With their use in the nuclear power plant the fuel cycle closes. In the case of the direct ultimate waste disposal, the entire fuel element including the valuable substances uranium and plutonium is disposed of as radioactive waste following an interim storage period to allow the short-lived radionuclides to decay and thus the heat development conditional on the decay to decline. For this purpose the fuel elements are sectioned in a conditioning plant, packed in containers suitable for final storage before being stored in a repository. Both methods - reprocessing and direct ultimate storage - have been thoroughly examined in Germany and the required processes and components have been developed. Radioactive waste must be stored safely for a long period and be kept away from biosphere. Under certain circumstances low and medium active liquid radioactive waste is fixed in cement following previous volume reduction by evaporation. Solid radioactive waste is burnt or compacted for volume reduction. For ultimate storage these products are packed in special barrels or containers. The highly active, heat-generating fission product solutions from reprocessing are vitrified in a well-tested procedure adding glass-forming substances and filled into stainless steel containers. Stable geological formations are used as repositories. In Switzerland and in Sweden granite rock is provided for this purpose and in Germany salt domes were investigated for ultimate waste disposal. Rock salt offers excellent properties for the ultimate disposal of heat-generating radioactive waste since it removes the heat well and has plastic behaviour, i.e. cavities gradually close and the waste is safely embedded.



Nuclear fuel cycle

Nuclear fusion

→fusion

Nuclear materials

According to the Euratom Safeguards Regulation the term 'nuclear materials' means any ore, source and special fissile material:

- 'Ores' means any ore containing, in such average concentration as shall be specified by the Council acting by a qualified majority on a proposal from the Commission, substances from which the source materials defined above may be obtained by the appropriate chemical and physical processing.
-
- 'Source materials' means uranium containing the mixture of isotopes occurring in nature; uranium whose content in uranium-235 is less than the normal; thorium; any of the foregoing in the form of metal, alloy; chemical compound or concentrate; any other substance containing one or more of the foregoing in such a concentration as shall be specified by the Council, acting by a qualified majority on a proposal from the Commission, and any other material which the Council may determine, acting by a qualified majority on a proposal from the Commission. The words 'source materials' shall not be taken to include ores or ore waste.
- 'Uranium enriched in uranium-235 or uranium-233' means uranium containing uranium-235 or uranium-233 or both in an amount such that the abundance ratio of the sum of these isotopes to

isotope 238 is greater than the ratio of isotope 235 to isotope 238 occurring in nature. 'Enrichment' means the ratio of the combined weight of uranium-233 and uranium-235 to the total weight of the uranium under consideration.

- 'Special fissile materials' means plutonium-239; uranium-233; uranium enriched in uranium-235 or uranium-233, and any substance containing one or more of the foregoing isotopes and such other fissile materials as may be specified by the Council, acting by a qualified majority on a proposal from the Commission; the expression 'special fissile materials' does not; however, include source materials nor ores or ore waste.

Nuclear material monitoring

Organisational and physical test methods enabling the monitoring of fissile material and detection of any impermissible removal. In Germany, nuclear material monitoring is performed by Euratom and IAEO.

Nuclear medicine

Application of open or enclosed radioactive substances in medicine for diagnostic or therapeutic purposes. In nuclear medicine functional diagnostics and localization diagnostics is distinguished. →radiology

Nuclear parent

Radioactive nuclide from which a nuclide (daughter product) results, e.g. Po-218 (nuclear parent) decays to Pb-214 (daughter product).

Nuclear poison

Substances with a large neutron absorption cross-section absorbing neutrons, an undesirable effect. Some of the fission products generated during fission have a high neutron absorption capacity, such as xenon-135 and samarium-149. The poisoning of a reactor by fission products may become so serious that the chain reaction comes to a standstill.

Nuclear power plant

Thermal power plant, primarily used for electricity generation, in which the nuclear binding energy released during the →nuclear fission in a reactor is converted to heat and subsequently into electrical energy via a water-steam circuit using a turbine and generator.

Nuclear power plants in Europe

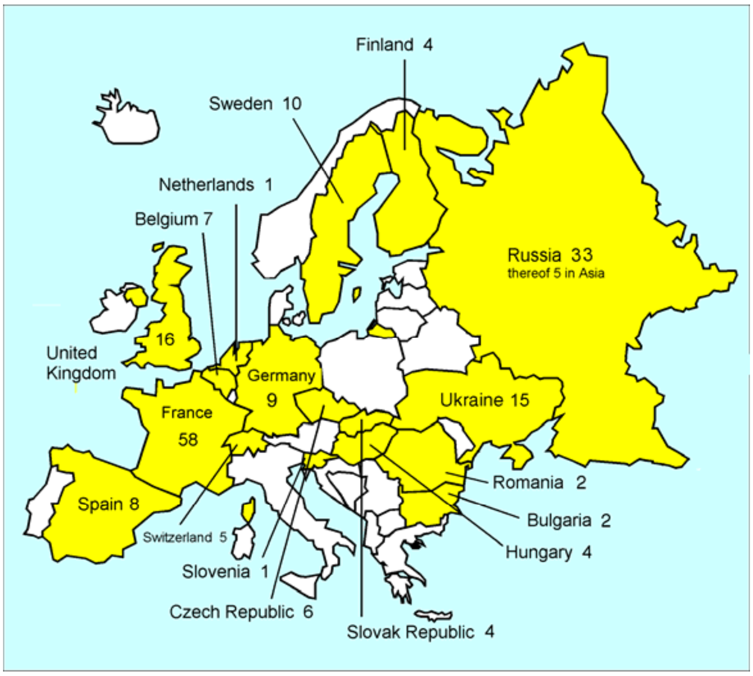
As of January 2013 there is a total of 185 nuclear power plant units with an installed electric net capacity of 162 GWe in operation in Europe (five thereof in the Asian part of the Russian Federation) and 17 units with an electric net capacity 15 GWe were under construction in five countries.

country	in operation		under construction	
	number	net capacity MWe	number	net capacity MWe
Belgium	7	5,927	-	-
Bulgaria	2	1,906	-	-
Czech Republic	6	3,766	-	-
Finland	4	2,736	1	1,600
France	58	63,130	1	1,600
Germany	17	12,068	-	-
Hungary	4	1,889	-	-
The Netherlands	1	482	-	-
Romania	2	1,300	-	-
Russian Federation	33	23,643	11	9,297

Slovakian Republic	4	1,816	2	782
Slovenia	1	688	-	-
Spain	8	7,567	-	
Sweden	10	9,395	-	-
Switzerland	5	3,263	-	-
Ukraine	15	13,107	2	1,900
United Kingdom	16	9,246	-	-
total	**185**	**161,922**	**17**	**15,179**

Nuclear power plants in Europe, in operation and under construction, as of January 2013

In terms of electricity generated by nuclear energy in 2011 France holds the top position with a share of 77.7 % followed by Belgium and the Slovakian Republic with 54.0 % and Ukraine with 47.2 %.



Nuclear Power Plants in Operation in Europe, January 2013

Nuclear power plants in Germany

In Germany (as of January 2013), nine nuclear power plants with an electric gross output of 12,696 MW are in operation. In 2012 they generated 100 billion kWh of electricity. The unit and energy availability amounted to 90 %.

nuclear power plant	type	gross capacity MWe	net capacity MWe	gross electricity generation 2012 MWh
GKN-2 Neckar	PWR	1,400	1,310	11,126,700
KBR Brokdorf	PWR	1,480	1,410	10,768,134
KKE Emsland	PWR	1,400	1,329	11,430,762
KKG Grafenrheinfeld	PWR	1,345	1,275	10,601,671
KKI-2 Isar	PWR	1,485	1,410	12,082,399
KKP-2 Philippsburg	PWR	1,468	1,402	10,778,670
KRB B Gundremmingen	BWR	1,344	1,284	10,366,208
KRB C Gundremmingen	BWR	1,344	1,288	10,613,396
KWG Grohnde	PWR	1,430	1,360	11,692,258
total		12,696	12,068	99,460,198

Nuclear power plants in operation in Germany, as of 2013-01-31 and their power generation in 2012

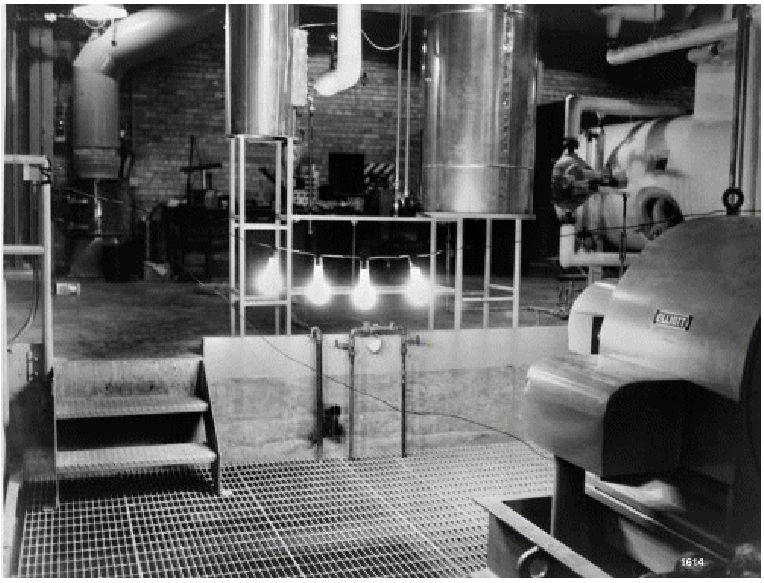
27 nuclear power plants - including experimental, prototype and demonstration facilities built in the 60s and 70s – have been decommissioned to date

name, location	electric gross output MW	operating period
HDR, Großwelzheim	25	1969-1971
KKN, Niederaichbach	107	1972-1974
KWL, Lingen	267	1968-1977
KRB-A, Gundremmingen	250	1966-1977
MZFR, Leopoldshafen	58	1965-1984
VAK, Kahl	16	1960-1985
AVR, Jülich	15	1966-1988
THTR, Hamm-Uentrop	307	1983-1988
KMK, Mülheim-Kärlich	1 308	1986-1988
KKR, Rheinsberg	70	1966-1990
KGR 1-5, Greifswald	2 200	1973-1990
KNK, Leopoldshafen	21	1977-1991
KWW, Würgassen	670	1971-1994
KKS, Stade	672	1972-2003
KWO, Obrigheim	357	1968-2005
Biblis A	1 225	1975-2011
Biblis B	1 300	1977-2011
GKN-1, Neckarwestheim	840	1976-2011
KKB, Brunsbüttel	806	1977-2011
KKI-1 Isar	912	1979-2011
KKK, Krümmel	1.402	1984-2011
KKP-1, Philippsburg	926	1980-2011
KKU, Unterweser, Stadland	1 410	1979-2011

Decommissioned nuclear power plants in Germany, as of 2013-01-31

Nuclear power plants, world-wide

On December 20, 1951, at the Experimental Breeder Reactor EBR-I in Arco, Idaho, USA, for the first time electricity - illuminating four light bulbs - was produced by nuclear energy. EBR-I was not designed to produce electricity but to validate the breeder reactor concept.



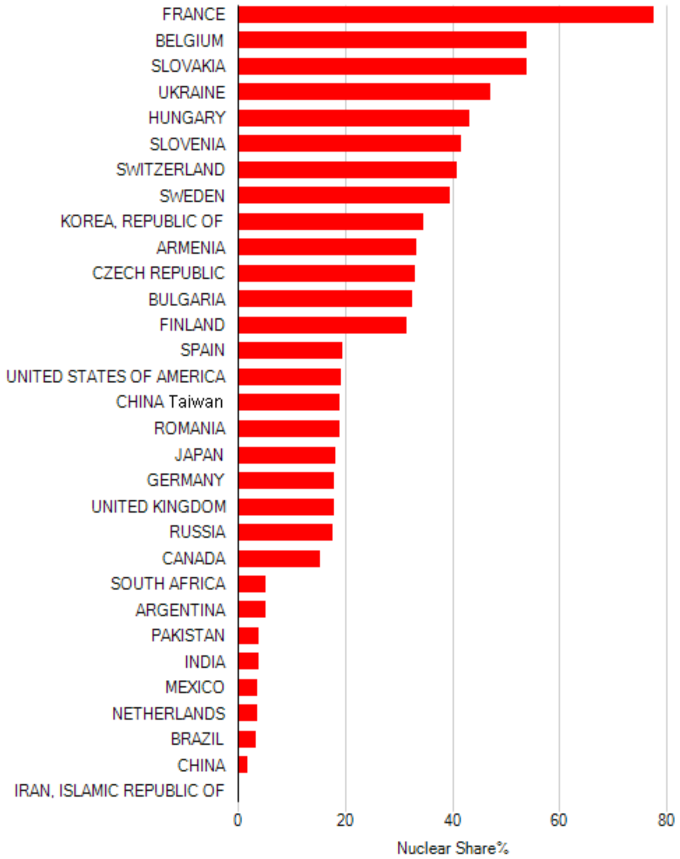
First electricity production by nuclear energy
Experimental Breeder Reactor EBR-I, 20 Dec.1951, Arco, Idaho, USA

On June 26, 1954, at Obninsk, Russia, the nuclear power plant APS-1 with a net electrical output of 5 MW was connected to the power grid, the world's first nuclear power plant that generated electricity for commercial use. On August 27, 1956 the first commercial nuclear power plant, Calder Hall 1, England, with a net electrical output of 50 MW was connected to the national grid.

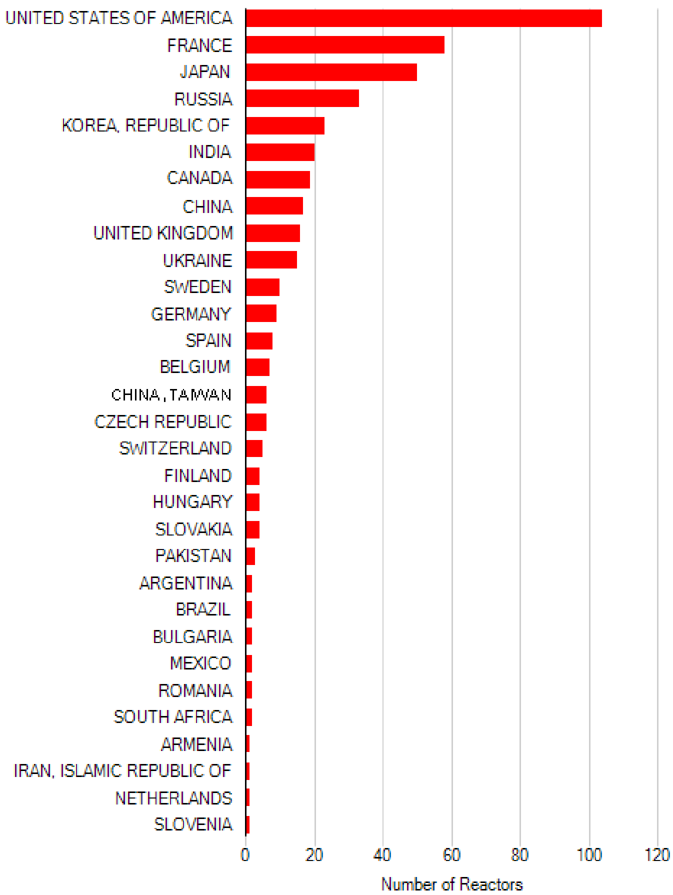
As of January 18, 2013 in 31 countries 437 nuclear power plant units with an installed electric net capacity of about 372 GW are in operation and 68 plants with an installed capacity of 65 GW are in 15 countries under construction. As of end 2011 the total electricity production since 1951 amounts to 69,760 billion kWh. The cumulative operating experience amounted to 15,080 years by end of 2012.

country	In operation		under construction	
	number	net capacity MWe	number	net capacity MWe
Argentina	2	935	1	692
Armenia	1	375	-	-
Belgium	7	5,927	-	-
Brazil	2	1,884	1	1,245
Bulgaria	2	1,906	-	-
Canada	19	13,665	-	-
China				
Mainland	17	12,816	29	28,753
Taiwan	6	5,018	2	2,600
Czech Republic	6	3,766	-	-
Finland	4	2,736	1	1,600
France	58	63,130	1	1,600
Germany	9	12,068	-	-
Hungary	4	1,889	-	-
India	20	4,391	7	4,824
Iran	1	915	-	-
Japan	50	44,215	3	3,993
Korea, Republic	23	20,754	4	4,980
Mexico	2	1,300	-	-
The Netherlands	1	482	-	-
Pakistan	3	725	2	630
Romania	2	1,300	-	-
Russian Federation	33	23,643	11	9,927
Slovakian Republic	4	1,816	2	782
Slovenia	1	688	-	-
South Africa	2	1,830	-	-
Spain	8	7,560	-	-
Sweden	10	9,395	-	-
Switzerland	5	3,263	-	-
Ukraine	15	13,107	2	1,900
United Arab Emirates	-	-	1	1,345
United Kingdom	16	9,246	-	-
USA	104	101,465	1	1,165
Total	**437**	**372,210**	**68**	**65,406**

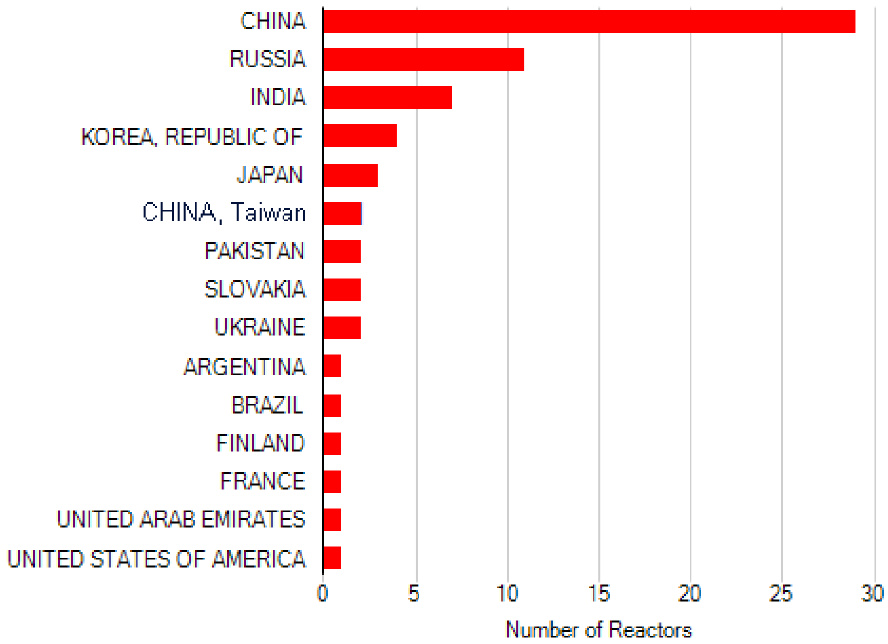
Nuclear power plants world-wide, in operation and under construction, IAEA as of 2013-01-18



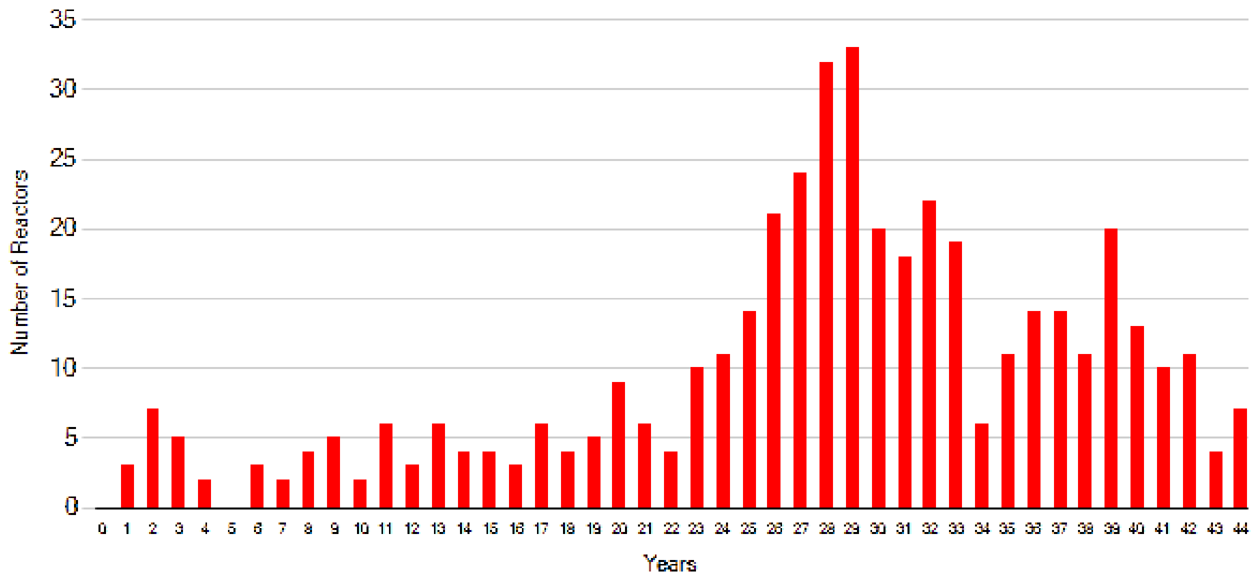
Nuclear share in electricity generation, 2011 (IAEA 2012, modified)



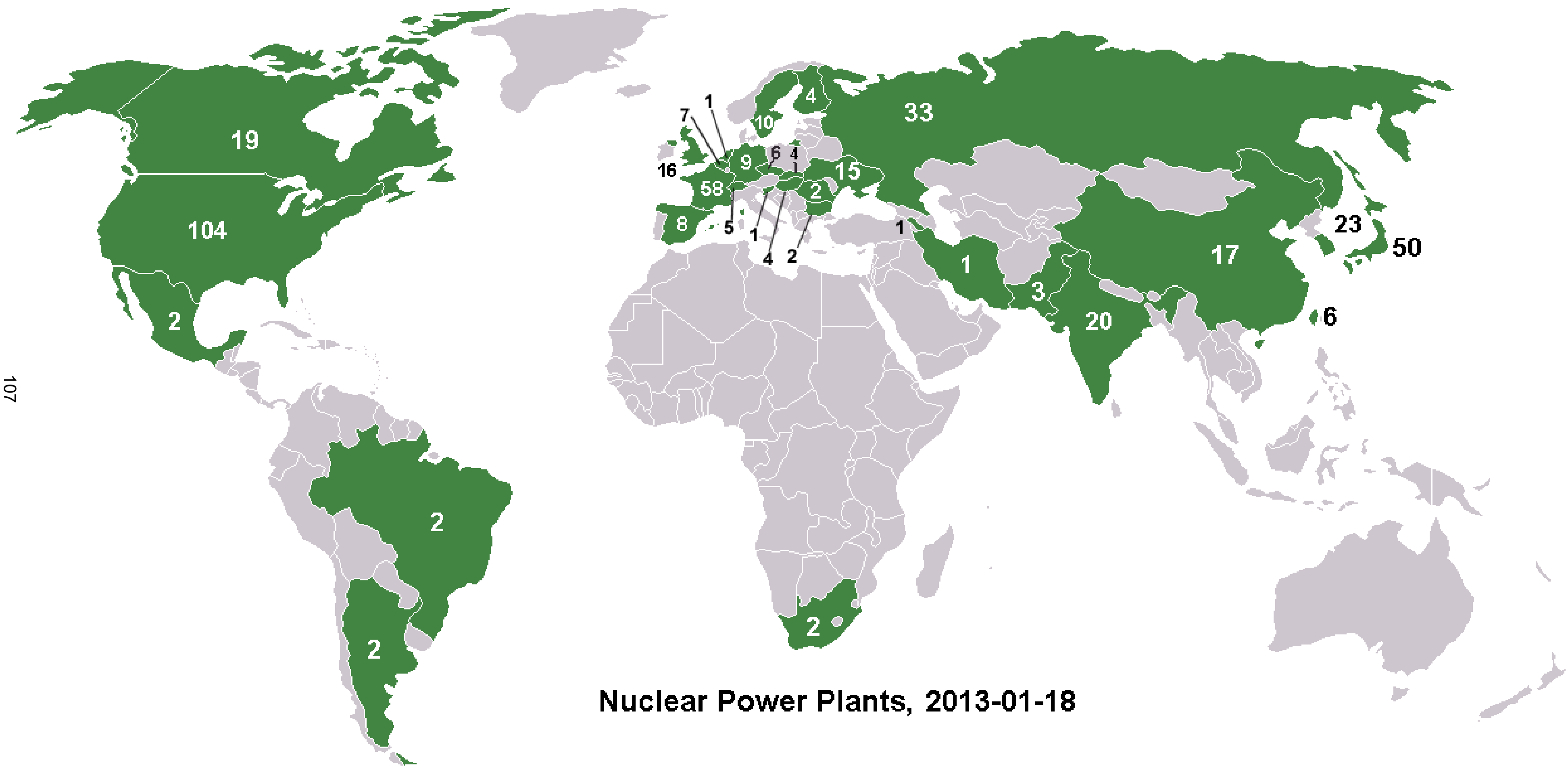
Number of reactors in operation, worldwide, 2013-01-18 (IAEA 2013, modified)



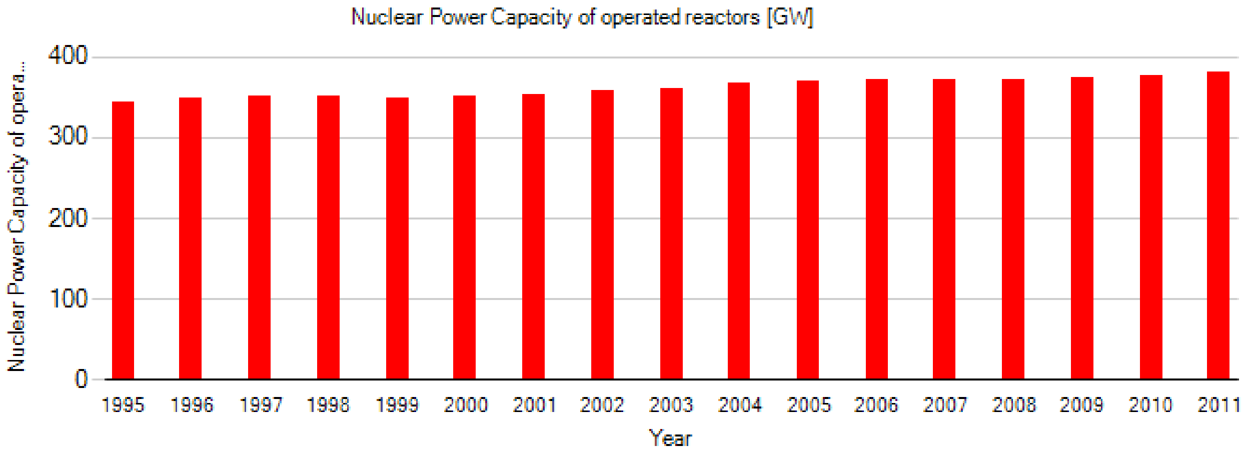
Number of reactors under construction, 2013-01-18 (IAEA 2013, modified)



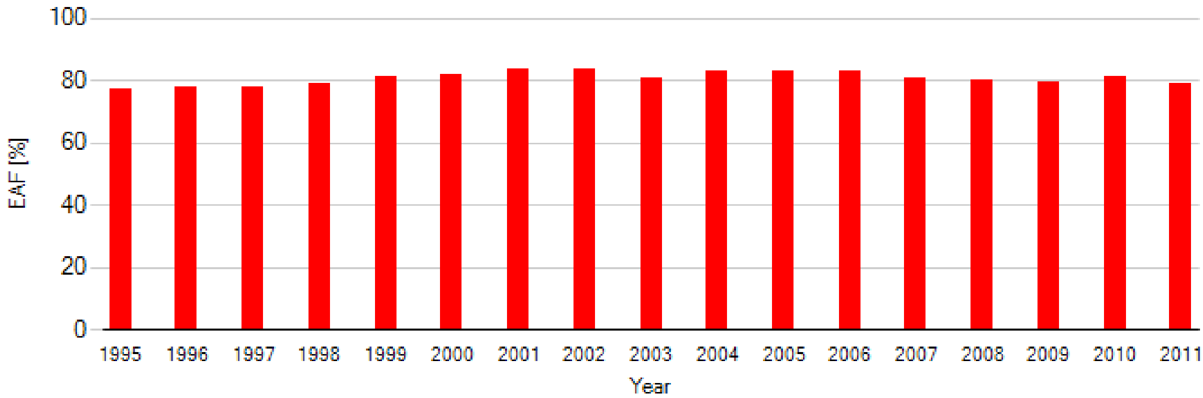
Number of nuclear reactors worldwide by age as of 2013-01-10 (IAEA 2013)



Nuclear Power Plants, 2013-01-18



Nuclear Power Plants, nuclear power capacity 1995 - 2011 (IAEA 2012)

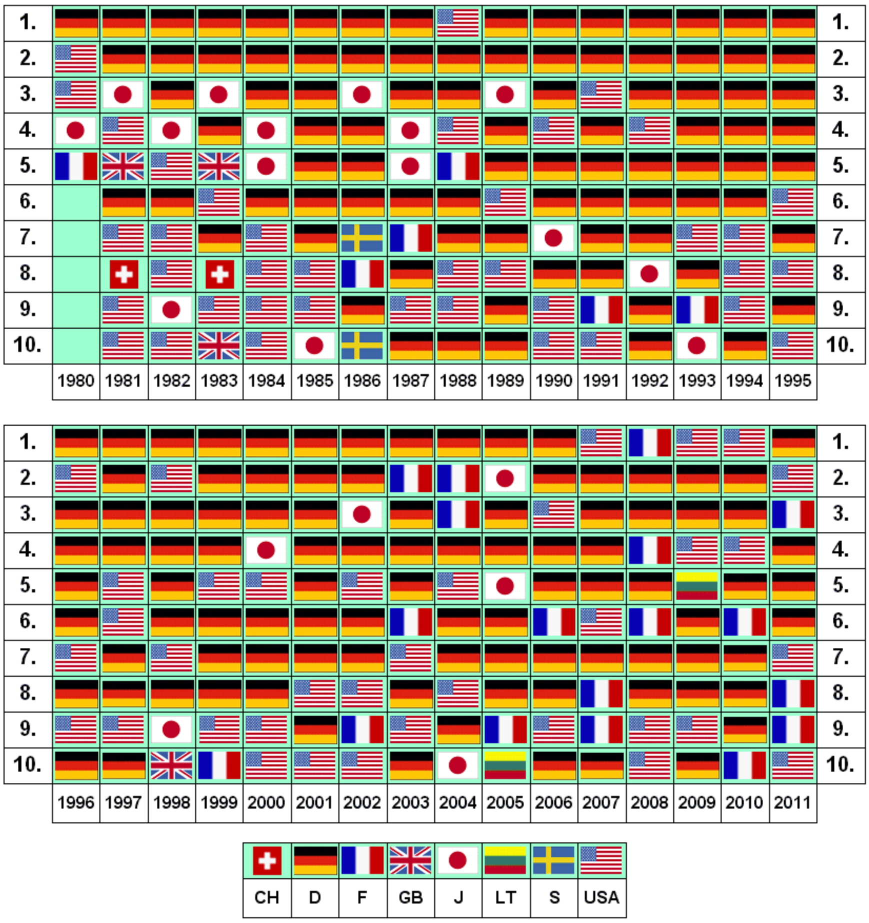


Nuclear Power Plants, energy availability factor 1995 - 2011 (IAEA 2012)

Nuclear power plants, world wide, in order of electricity generation

Country	Nuclear power plant	gross capacity MWe	Gross electricity generation, bn kWh
Germany	Isar 2	1,485	12.307
USA	Palo Verde 3	1,428	11.976
France	Chooz B 2	1,560	11.927
Germany	Emsland	1,400	11,559
Germany	Neckarwestheim II	1,400	11.555
Germany	Philippsburg 2	1,468	11.314
USA	South Texas 1	1,413	11.122
France	Civaux 2	1,561	11.100
France	St. Alban/St. Maurice 2	1,381	11.006
USA	Palo Verde 2	1,431	11.005

Nuclear power plants world-wide according to their electricity generation in 2011



Nuclear power plants world-wide according to their electricity generation, 1980 - 2011

Nuclear power plants, world-wide, reactor types

Mainly pressurized water reactors (PWR) are used in the nuclear power plants world-wide – 62 % according to the number, 68 % according to the output - followed by boiling water reactors (BWR) – 19 % according to the number, 21 % according to the output.

reactor type	operational	
	number	electr. net output MW
PWR	273	251,418
BWR	84	77,737
CANDU/D_2O-PWR	48	24,201
GGR/AGR	15	8,055
RBMK	15	10,219
FBR	2	580
Total	**437**	**372,210**

Nuclear Power Plants, world-wide, reactor types, IAEA 2013-01-18

Nuclear reactor

→reactor

Nuclear reactor telemonitoring system

Measuring system to record emission and radiation dose values as well as operating parameters of nuclear power plants and remote data transmission for processing and evaluation of the data by the central monitoring authority.

Nucleon

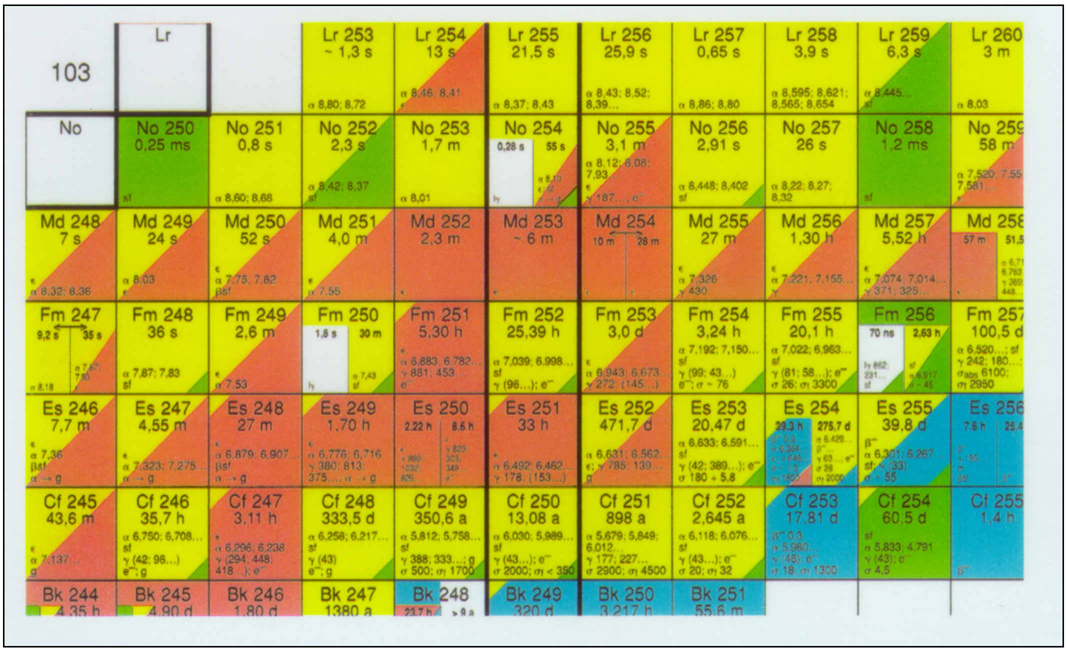
Joint name for proton and neutron.

Nucleus

Positively charged nucleus of an atom. Its diameter amounts to some 10^{-13} (ten trillionths) of a cm, i.e. around 1/100 000 of the atom's diameter. It contains almost the total mass of the atom. The nucleus of an atom, apart from the nucleus of normal hydrogen, is made up of →protons and →neutrons. The number of protons determines the nucleus charge or atomic number Z, the number of protons plus neutrons - the nucleons - the nucleon or mass number M of the nucleus.

Nuclide chart

Graphic representation of nuclides indicating the essential data of decay type, half-life, energies of emitted radiation; normally shown in a rectangular system of coordinates with the atomic number as ordinate and the neutron number as abscissa. Most recent version 8th Edition 2012 published by Nucleonica GmbH, c/o European Commission, 76344 Eggenstein-Leopoldshafen, Germany
www.nucleonica.com/wiki/index.php?title=Category:KNC



Extract from the „Karlsruhe nuclide chart“

Nuclide

A nuclide is a type of atom characterized by its proton number, neutron number and its energy condition. Conditions with a life of less than 10^{-10} s are called excited conditions of a nuclide. At present, approximately 4 000 experimentally observed nuclides and isomers are known, distributed over the 118 currently known elements. More than 3 700 nuclides of these are radioactive. →radionuclides

O

Off-gas treatment

Off-gases from nuclear plants are basically treated in the following sequence:

- Wet gases: washing in columns and/or Venturi washers, wet filtering, drying, absolute filtering through aerosol filter of special class S, off-gas blower,
- Dry gases: prefiltering, absolute filtering through aerosol filter of special class S, off-gas blower,
- Hot gases from the combustion of radioactive waste: post-burning and dust retention in sinter ceramic candles (temperature up to 1000 °C), post-filtering with sintered ceramic or sintered metal filters at temperatures up to 700 °C, further purification as for dry gases. Iodine and ruthenium require special measures.

Oklo

A prehistoric natural „nuclear reactor“, which was in operation about 2 bn years ago, was discovered in the uranium deposit Oklo/Gabon in 1972. In past years, six further locations in this deposit were found where a self-perpetuating chain reaction must have taken place due to the reduced U-235 content in the natural uranium. For the Oklo II location, it can be calculated from the depletion of uranium-235 entailed by fission that a minimum of 4 t U-235 must have been fissioned, 1 t Pu-239 formed, and a volume of heat of about 100 bn kWh generated. As a comparison: in the reactor of a nuclear power plant of the 1 300 MWe category, about 30 bn kWh heat is generated by fission annually.

Open radioactive substances

Radioactive substances which are not enclosed, i.e. surrounded by a firm inactive shell or embedded in solid inactive substances so that the release of radioactive substances is prevented in the case of usual normal stress.

Operating experience with nuclear power plants

437 nuclear power plant units with a total electrical net output of 372 GW were in operation in 31 countries in January 2013. The cumulative operating experience amounted to 15,080 years by end of Dec. 2012. →nuclear power plants, world-wide

Operating hours

The operating hours (utilization period) are equal to the gross energy generated in a period of time divided by the maximum load in this period.

Operating manual

An operating manual comprises all instructions necessary for the operation and maintenance of a process-related plant. It contains notes for the organization of the operation and instructions for the behaviour of the plant personnel during operational malfunctions, incidents and other events.

Organ committed dose

The organ committed dose $H_T(\tau)$ for an incorporation at the time t_0 is the time integral of the organ dose rate in the tissue or organ T:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)\,dt$$

$\dot{H}_T(t)$ average organ dose rate in tissue or organ T at the time t

τ period in years over which the integration is effected. If no value is indicated for τ, a period of 50 years for adults and the period from the respective age to the age of 70 years for children are taken as a basis.

The unit of the organ committed dose is sievert (symbol: Sv).

Organ dose

The organ dose $H_{T,R}$ is the product of the organ absorbed dose $D_{T,R}$ averaged over the tissue/organ T generated by the radiation R and the →radiation weighting factor w_R.

$$H_{T,R} = w_R \times D_{T,R}$$

If the radiation consists of types and energies with different w_R values, the individual values are added. The following applies for the organ dose in this case:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

„Otto Hahn"

German merchant ship with 16 870 GRT built for the trial of nuclear marine propulsion. A pressurized water reactor with a thermal power of 38 MW was used for propulsion. First nuclear voyage on 11th Oct. 1968. By the end of 1978, the ship travelled 642 000 nautical miles and transported 776 000 t freight. The „Otto Hahn" was shut down in 1979 and the reactor system and all radioactive parts were disassembled and removed. The ship subsequently re-entered service following incorporation of conventional propulsion.

Output, specific

Measure for the heat output per mass unit of the nuclear fuel generated in the reactor core and removed from the core (e. g. Nuclear Power Plant Emsland: 37.4 kW/kg uranium).

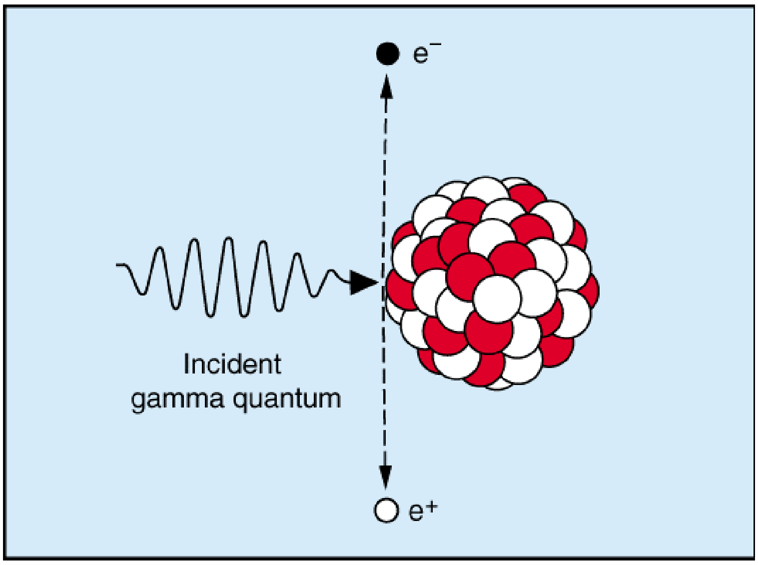
Overheating

The heating of →saturated steam to superheated steam. In power plants, this process is applied to improve the efficiency and to reduce condensation in the turbines.

P

Pair generation

Interaction of energy-rich electromagnetic radiation with matter. If the energy of a radiation is greater than 1.02 MeV and thus greater than double the →rest mass of an electron ($m_{e,0}$ = 0.511 MeV), it is possible to generate an electron-positron pair (materialisation of energy).



Pair generation; formation of an electron-positron pair from a gamma quantum rich in energy

Paris Convention

→Convention on Third Party Liability in the Field of Nuclear Energy.

Partial body dose

Average value of the dose equivalent over the volume of a body section or an organ; in the case of the skin, over the critical range (1 cm^2 in the range of the maximum dose equivalent in 70 micrometer depth).

Particle accelerator

→accelerator

Partition wall process

→diffusion separation process

Party responsible for radiation protection

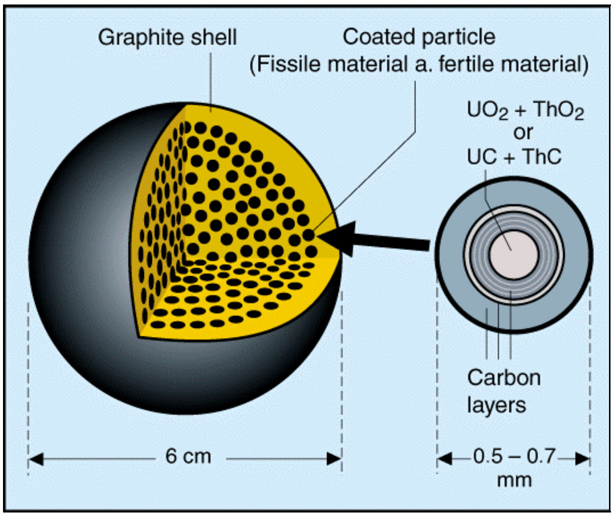
A party responsible for radiation protection involves anyone who carries out activities which in accordance with the Atomic Energy Act, the Radiation Protection Ordinance or the X-ray Ordinance require a permit or require notification or who searches, mines or conditions radioactive minerals. The duties imposed on a party responsible for radiation protection start immediately with the assumption of the activity.

Peak load power plants

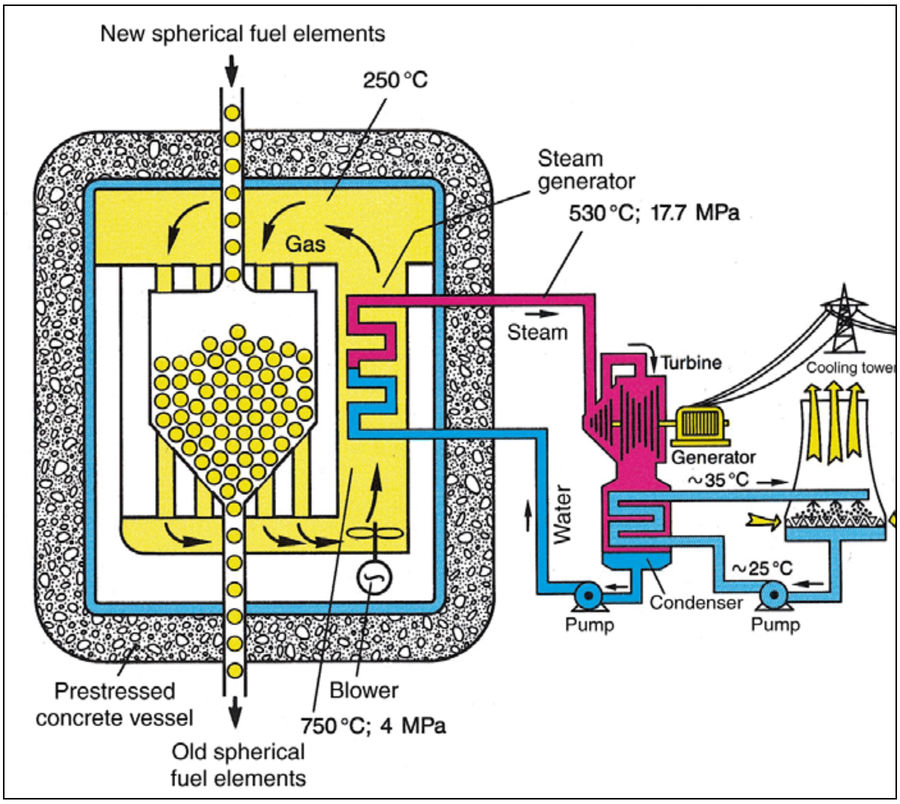
Power plants for electricity generation which, due to their operational and economic properties, are used to cover the peak load. Gas turbines and storage and pumped storage power plants are used as peak load power plants.

Pebble bed reactor

Gas-cooled high-temperature reactor with a core of spherical fuel and moderator (graphite) elements. The decommissioned nuclear power plants AVR in Jülich and THTR-300 in Uentrop had a pebble bed reactor. The THTR-300 contained about 600 000 spherical fuel and moderator elements. The fuel elements consist of a kernel of U-235 and thorium surrounded by a graphite matrix of a diameter of 6 cm.



Schematic representation of the spherical fuel element of a pebble bed reactor



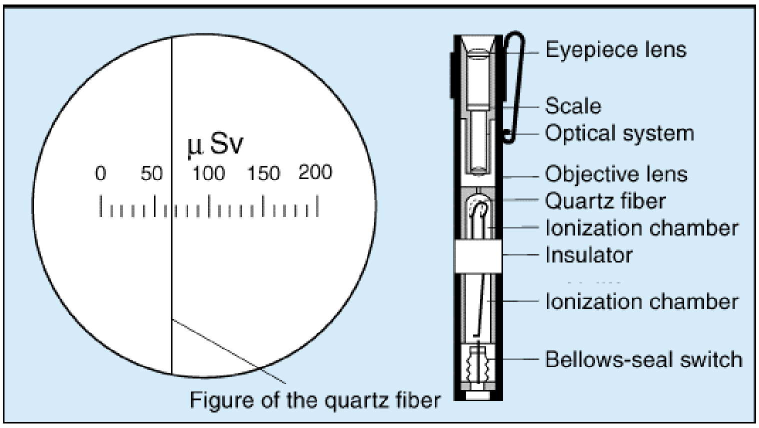
Nuclear power plant with pebble bed reactor

Pellet

Sintered nuclear fuel tablets of a diameter of 8 to 15 mm and a length of 10 to 15 mm. Many such pellets are filled into the 4 m long fuel cladding tubes.

Pen dosimeter

Pen-shaped measuring device to determine the dose of ionizing radiation. The discharge of a charged condenser is a measure of the dose received by the carrier of a dosimeter.



Pen dosimeter

Period

→reactor period

Personal dose

The Radiation Protection Ordinance requires measurement of the personal dose for determination of the body dose. The personal dose is the dose equivalent measured in the measuring variables of →depth dose and →skin dose at a spot representative of radiation exposure at the body surface. The depth personal dose in the case of whole body exposure to penetrating radiation is an estimated value for the effective dose and the organ doses of deep organs and the skin dose an estimated value for the skin dose. →dose

Persons exposed to radiation in their work

According to the provisions of the Radiation Protection Ordinance of 2001 and the X-ray Ordinance of 2002 these are persons who may receive an effective dose (→ dose, effective) of more than 1 mSv per year. The group of persons exposed to radiation in their work is classified into category A persons, who may receive more than 6 mSv per year, and category B persons, who may receive between one and six Millisieverts per year. The frequency of examinations within the scope of medical monitoring depends on the respective classification.

The number of persons exposed to radiation in their work who were monitored in 2008 using official person dosimeters in Germany amounted to a total of 323,500, 77 % of these persons working in the medical sector.. The average annual personal dose of all persons monitored amounted to 0.14 mSv. When evaluating this average value it must be noted that the value measured was below the lower measuring limit of the personal dosimeter of 0.05 mSv for the majority of all persons monitored (83 %) during the whole year. In these cases the measuring points for the personal dose determined the value zero. Averaging the annual personal dose values which differ from zero for the persons monitored results in a mean annual personal dose of 0.8 mSv (by comparison: the natural radiation exposure in Germany amounts to an annual average of 2.1 mSv). The sum total of the annual dose values of all persons monitored (collective dose) amounted to 46 man-sievert in 2008. All of these dose values relate to photon radiation, since this determines the dose in almost all control areas. Dose contributions by neutron and beta emitters are only significant in a few cases.

According to the German Radiation Protection Ordinance the radiation exposure of airline personnel due to the higher cosmic radiation exposure flying in high altitudes has to be calculated and registered. The total dose for these 37,000 persons amounted in 2008 to 85 Sv, the calculated average dose is 2.3 mSv.

Phosphate glass dosimeter

Measuring device to determine the dose. The radio-photoluminescence effect which is the property of certain substances to emit fluorescent light of greater wave length upon irradiation with ultraviolet light when previously exposed to ionizing radiation is used to determine the dose. Silver-activated metaphosphate glasses - glasses made of alkaline and alkaline earth phosphates with some percent of silver metaphosphate - show this photoluminescence effect for example. The intensity of the fluorescent light is proportional over wide areas of the irradiated dose.

Photo-cathode

Cathode where electrons are released by the photoelectric effect.

Photo-effect

Interaction of roentgen and gamma radiation with matter. The roentgen or gamma quantum transfers its energy to the shell electron of the atom. The electron receives kinetic energy which is equal to the energy of the quantum reduced by the binding energy of the electron.

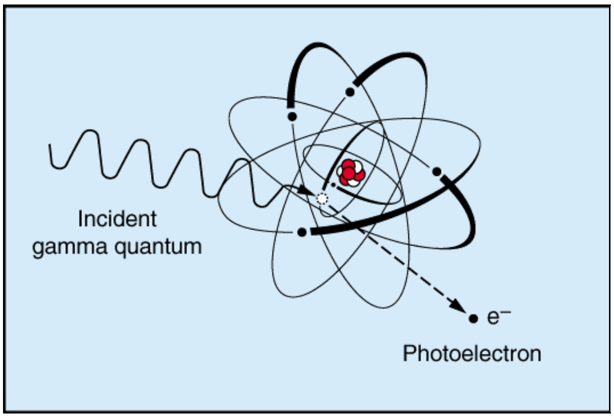


Photo-effect

Photon

Energy quantum of electromagnetic radiation. The rest mass of the photon is equal to zero. It has no electrical charge. →elementary particle

PHWR

Pressurized Heavy Water Reactor; example: Atucha, Argentina, 367 MWe.

2 pi-counter

Radiation detector capable of detecting the radiation of a radioactive source over a solid angle of 2π.

4 pi-counter

Radiation detector capable of detecting the radiation of a radioactive source over the full solid angle of 4π.

Pi meson

→pion, →elementary particle.

Pinch effect

Effect in controlled fusion experiments in which electric current flowing through a plasma column constricts, compresses and thereby heats the plasma.

Pion

Short-lived elementary particle; short for pi meson. The mass of a charged pion is about 273 times that of an electron. An electrically neutral pion has a mass which is 264 times that of the electron. →elementary particle

Plasma

Electrically neutral gas mixture of ions, electrons and neutral particles. High-temperature hydrogen plasmas are used as fuel in experiments of controlled →fusion.

Plateau

Part of the counter tube characteristic curve in which the counting rate changes only slightly in the case of voltage fluctuations.

Plutonium

Plutonium - the 94th element in the classification of elements - was discovered in 1940 by the American researchers Seaborg, McMillan, Wahl and Kennedy as second transuranium element of the plutonium-238 isotope upon bombardment of uranium-238 with deuterons. Today 15 Pu-isotopes are known. Due to its property as fissile material, the isotope Pu-239 (half-life 24 110 years) is of specific importance. The elements 93 and 94 following the 92nd element - uranium - in the classification of elements have been named analogously to uranium, which is named after the planet Uranus, 'neptunium' and 'plutonium', the planets Neptune and Pluto following Uranus. Plutonium is generated by neutron capture in uranium-238 and two subsequent beta decays according to the following scheme:

U-238 + n ⇒ U-239 ⇒ ß-decay ⇒ Np-239 ⇒ ß-decay ⇒ Pu-239.

In nature, plutonium-239 occurs in tiny quantities in minerals containing uranium (pitchblende, carnotite) - one Pu atom per 1 trillion and more uranium atoms. It is formed from U-238 by neutron capture released upon the spontaneous fission of U-238. In above-ground nuclear weapon tests, approx. six tonnes Pu-239 were released into the atmosphere and distributed all over the world, so that in Central Europe for example, about 60 Bq Pu-239 pro m^2 have been deposited. Plutonium is a radiotoxic substance and its chemical toxicity as a heavy metal is therefore negligible. The radiotoxic effect of plutonium is very serious in the case of inhalation of the finest Pu aerosols; ingestion of plutonium is about 10 000 times less dangerous, since only 1/100 percent of plutonium is absorbed by the intestinal mucosa, 99.99% is excreted immediately.

Poison

→nuclear poison

Poisoning

Some of the fission products generated during the operation of a reactor have a large capture cross-section for neutrons (e.g. Xe-135). The control device must be adjusted to compensate for the reactivity equivalent of the reactor poisons to keep the reactor at its power level. Reactor poisons (e.g. boron acid solution) are injected into water-moderated reactors for emergency shutdown. Boric acid solution is used to compensate for excess reactivity in pressurized water reactors.

Pollux

Container for direct ultimate waste disposal of spent fuel elements. Naming relates to →Castor® (transport and interim storage container for spent fuel elements) after the twin brothers Castor and Pollux of the Greek legend. The concept of direct ultimate waste disposal provides that spent fuel elements be compacted, packaged in tightly closed containers and safely stored in repositories isolated from the biosphere. For reference test, a container with a design of the „Pollux" type has been developed which can hold up to eight pressurized water reactor fuel elements. It has a diameter of about 1.5 m, a length of approx. 5.5 m and a weight of 64 tonnes when loaded. The container is equipped with a double shell and ensures the safe inclusion of radionuclides. An internal container to accommodate the compacted fuel elements - separated by a neutron moderator - is surrounded and protected by an external shield container made of spheroidal iron. The Pollux container system is designed in compliance with the traffic law regulations for type B(U) packings and the atomic energy law for interim storage of nuclear fuel. The containers can therefore be used as transport, interim storage and ultimate waste containers.

Pool reactor

Reactor in which fuel elements are submerged in an open water pool. The water serves as a moderator, reflector and coolant. This reactor type is used for research and training purposes.

Positron

Elementary particle with the mass of an electron, but positively charged. It is the „anti-electron“ generated during pair creation and emitted during beta plus decay.

Power generation from nuclear plants in Europe

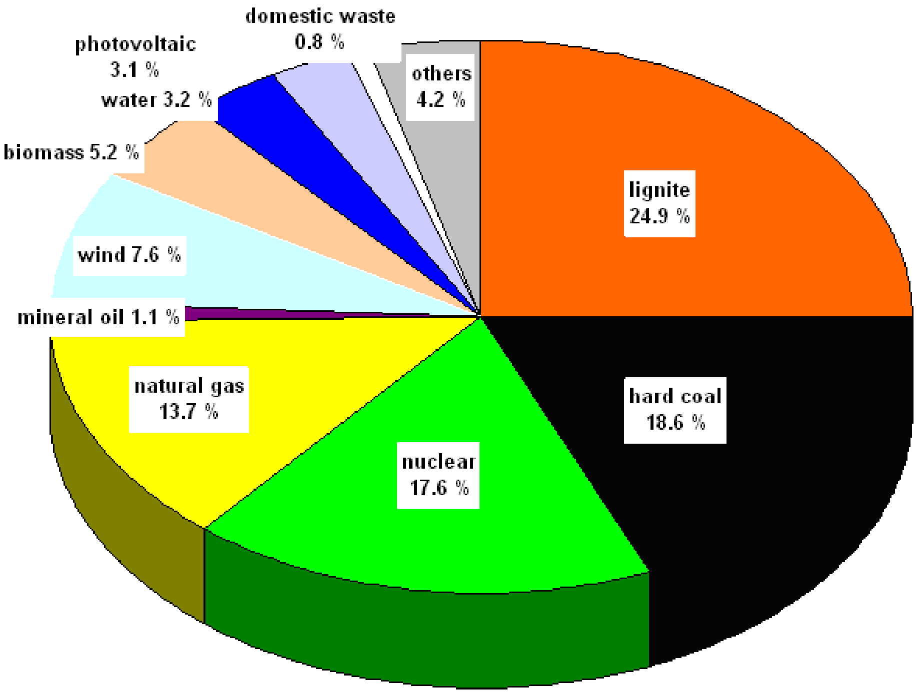
869 billion kWh of electricity were generated from nuclear power in the European Union in the year 2010.

Country	Production from nuclear power in bn. kWh	Nuclear power share (%)
Belgium	45.7	52
Bulgaria	15.2	34
Czech Republic	26.4	33
Germany	133.0	23
Finland	21.9	29
France	407.9	74
Great Britain	56.4	16
Hungary	14.8	42
Netherlands	3.7	3
Romania	10.7	20
Russian Federation	*155.2*	*17*
Sweden	55.1	39
Switzerland	*25.3*	*39*
Slovakia	13.5	52
Slovenia	5.4	37
Spain	59.3	20
Ukraine	*83.8*	*49*
Total	1133.3	-
Total EU	869.0	-

Electricity production in European countries with nuclear power plants, 2010

Power generation, Germany

In 2011 the gross electric power generation in Germany totalled 615 billion kWh. A major proportion of the electricity supply is based on lignite (24.9 %), hard coal (18.6 %) and nuclear energy (17.6 %). Natural gas has a share of 13.7 %. Renewables (wind, water, biomass, photovoltaic) account for 19.9 %.



Gross electricity production by energy sources, Germany 2011

Power generation, nuclear power plants in Germany

In 2010, a total of 140.5 bn kWh were converted from nuclear energy into electrical energy in German nuclear power plants, corresponding to a share of 22.6 % of the electricity supply in Germany. Ranking highest was the Nuclear Power Plant Isar 2 with 12 bn kWh. In Germany, electricity has been generated from nuclear power since 1961.

Year	electricity production 10^9 kWh
1961	0.024
1970	6.0
1980	42.6
1990	146.1
2000	168.5
2005	163.0
2010	140.5

Electricity production from nuclear power plants in Germany

Power generation, nuclear power plants world-wide

The global electricity generation from nuclear energy amounted to about 2,517 billion kWh in 2011. The total nuclear energy production since start up in 1951 till 2011 amounts to 69,760 billion kWh.

Power reactor

A nuclear reactor suitable for use in a nuclear power plant, in contrast to reactors which are mainly used for research purposes or to generate fissile material. Power reactors have a thermal output of up to 5 000 MW corresponding an electric output of 1 500 MW. →boiling water reactor, →pressurized water reactor

ppb

parts per billion, 1 part per 1 billion parts. Measure of the degree of impurities in solid bodies, liquids and gases.

ppm

parts per million, 1 part per 1 million parts. Measure of the degree of impurities in solid bodies, liquids and gases.

Pressure tube reactor

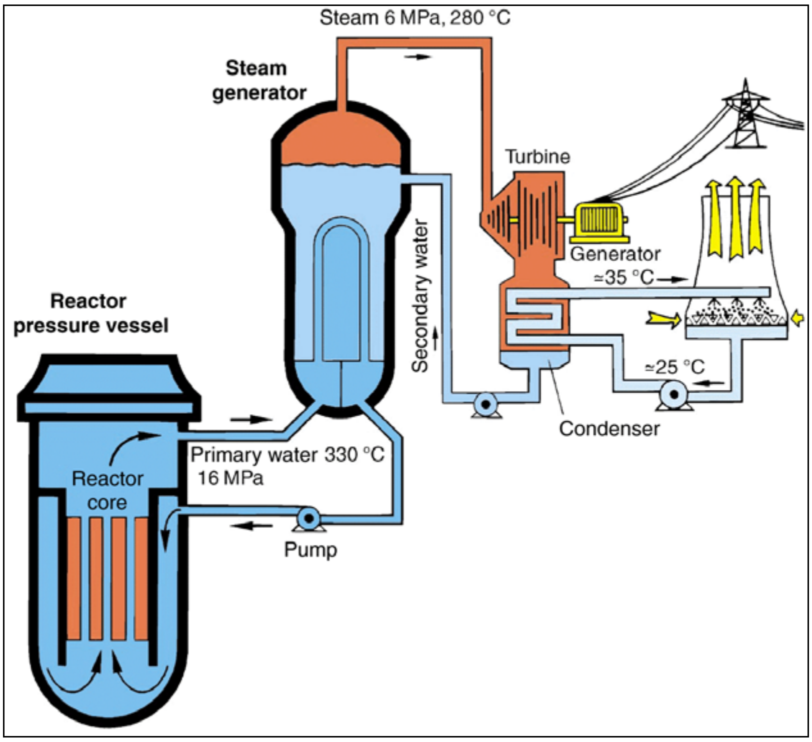
Nuclear reactor in which the fuel elements are contained within many tubes through which the coolant is circulated. This tube arrangement is surrounded by the moderator. In the Canadian CANDU reactor type, heavy water (D_2O) is used as a coolant and moderator; in the Russian RBMK reactor type, light water (H_2O) is used as coolant and graphite as a moderator.

Pressure vessel

Thick-walled cylindrical steel vessel enclosing the reactor core in a nuclear power plant. The vessel is made of a special fine-grained steel well suited for welding and with a high toughness while showing low porosity under neutron irradiation. The inside is lined with austenitic cladding to protect against corrosion. For a 1 300 MWe pressurized water reactor, the pressure vessel is about 12 m high, the inner diameter is 5 m, and the wall of the cylindrical shell is about 250 mm thick. The overall weight amounts to approx. 530 t without internals. The vessel is designed for a pressure of 17.5 MPa (175 bar) and a temperature of 350 °C.

Pressurized water reactor

Power reactor in which the heat is dissipated from the core using highly pressurized water (about 160 bar) to achieve a high temperature and avoid boiling within the core. The cooling water transfers its heat to the secondary system in a steam generator. Example: Grohnde Nuclear Power Plant with an electrical output of 1 430 MW.



Nuclear power plant with pressurized water reactor

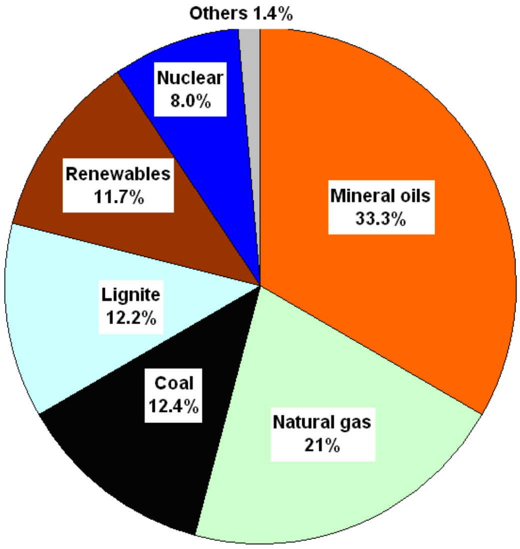
Primary energy

Energy raw materials in their natural form prior to any technical conversion, e.g. coal, lignite, mineral oil, natural gas, uranium, water, solar radiation.

Primary energy consumption, Germany

Primary energy refers to the energy carriers at the beginning of the energy conversion chains. The total primary energy consumption in Germany amounted to 461 million t of coal equivalents in 2012. The consumption is divided up as follows:

Mineral oils	33.3 %
Natural gas	21.0 %
Hard Coal	12.4 %
Lignite	12.2 %
Renewables	11.7 %
Nuclear energy	8.0 %
Others	1.4



Primary energy consumption, Germany, 2012

Primary energy reserves

Reserves are the economically usable part of energy stock. The presently non-economically usable part is known as resources. The global energy reserves total more than 1 350 billion tonnes of coal equivalents. The table shows the distribution over the various energy carriers and global regions.

area	crude oil	gas	coal	uranium (80 $/kg)	%
Europe	3	5	40	marginal	3.6
CIS	25	81	150	6	19.5
Africa	26	19	29	2	5.6
Near East	154	103	1	-	19.3
Austral-Asia	8	22	308	19	26.5
North America	48	13	211	6	20.6
Latin America	44	10	9	3	4.9
World	308	253	748	36	

Global energy reserves in billion tonnes of coal equivalent, 2011

Proliferation

Distribution (of nuclear weapons). All measures of international nuclear material monitoring serve the non-proliferation of nuclear weapons stipulated in the Treaty on the Non-proliferation of Nuclear Weapons. This treaty has been in force for Germany since the 2nd May 1975.

Proportional counter

Detection device for ionizing rays. The proportional counter supplies proportional output pulses for primary ionization so that alpha and beta rays due to their different specific ionization can be traced separately. The proportional counter allows determination of the energy of radiation.

Proton

Elementary particle with a positive electrical elementary charge and a mass of $1.67262158 \cdot 10^{-24}$ g, which is equal to about 1836 times the electron mass. Protons and neutrons together form the atomic nucleus. The number of protons in the atomic nucleus is determined by the chemical element allocated to this atom. →elementary particle

Pulsed column

Column-shaped extraction apparatus pressing two liquids through sieves pulsewise in a countercurrent („pulse plates“ or „sieve bottoms“) during which certain elements change over from one liquid phase to the other.

Pulsed reactor

Type of research reactor used to produce short, intensive power and radiation impacts. The neutron flux density in such a pulse is much higher than could be achieved in the stationary state. Example: FRMZ, research reactor of the university of Mainz, type TRIGA-Mark-II; pulse power 250 MW, permanent power 0.1 MW.

Pure element

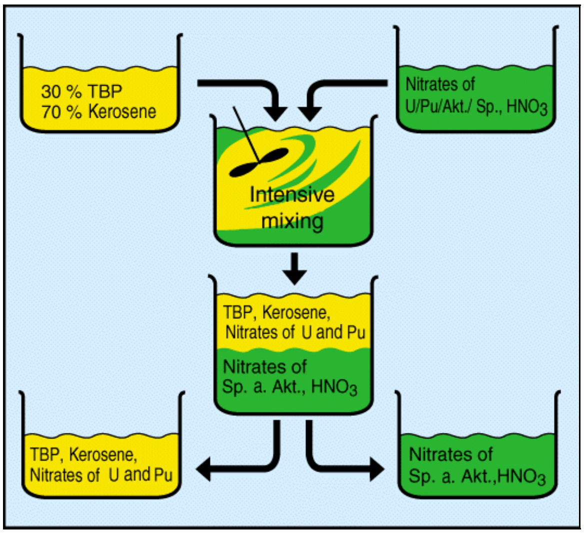
Chemical element consisting of only one stable isotope; e.g. fluorine, aluminium, gold.

PUREX

Plutonium and **U**ranium **R**ecovery by **Ex**traction. →PUREX process

PUREX process

Process for the reprocessing of spent nuclear fuel to separate uranium and plutonium from the fission products and from one another. Following the dissolution of the irradiated fuel in nitric acid, uranium and plutonium are maintained in the organic phase by organic solvent extraction - 30 percent tributyl phosphate (TBP) in kerosene is used as organic solvent - while the fission products remain in the aqueous nitric phase. Further process steps enable the subsequent separation of uranium and plutonium from one another.



Principle of the PUREX process for the separation of U and Pu from fission products

PWR

→pressurized water reactor

Q

Quality assurance

Assurance of the quality of materials, apparatuses, containers, piping, etc. is a vital prerequisite for the licensing of nuclear facilities. The measures required by the licensor are covered in a quality programme. Preliminary, construction and acceptance tests are carried out by independent experts.

Quality factor

Term of radiation dosimetry. The quality factor was introduced to define the dose equivalent based on the fact that the probability of stochastic radiation effects not only depends on the absorbed dose but also on the radiation type. The quality factor considers the influence of the different energy distribution - which varies according to the different types of rays - in the cellular area in the irradiated body. Quality factor Q is a function of the unrestricted linear energy transfer L. The following relation has been fixed between the quality factor and the unrestricted linear energy transfer L:

Unrestricted linear energy transfer L in water, (keV μm^{-1})	$Q(L)$
$L \leq 10$	1
$10 < L < 100$	$0.32\ L - 2.2$
$L \geq 100$	$300 / \sqrt{L}$

Relation between the linear energy transfer and the quality factor

R

R

Symbol for →roentgen.

rad

Former unit of absorbed dose (rad: radiation absorbed dose); symbol: rd or rad. One rad is equal to the absorption of a radiation energy of 1/100 joule per kilogram matter. The new unit of the absorbed dose is joule/kilogram with the special unit name gray, symbol: Gy. 1 rd = 1/100 Gy.

Radiation

Energy dispersion through matter or space. In atomic physics this term is also extended to fast moving particles (alpha and beta radiation, free neutrons, etc.).

Radiation biology

Branch of radiology dealing with the mechanisms of action and effects of radiation, in particular ionizing radiation, on biological systems, i.e. on subcellular and cellular levels as well as on the levels of cell systems and organisms. Tasks:

- Application of radiation to investigate biological phenomena,
- Application of radiation to clarify tumour growth and radiation treatment fundamentals,
- Elaboration and improvement of fundamentals for the assessment of somatic and genetic risks and implementation of results,
- Elaboration and improvement of fundamentals to identify and modify radiation-related diseases.

Radiation, characteristic

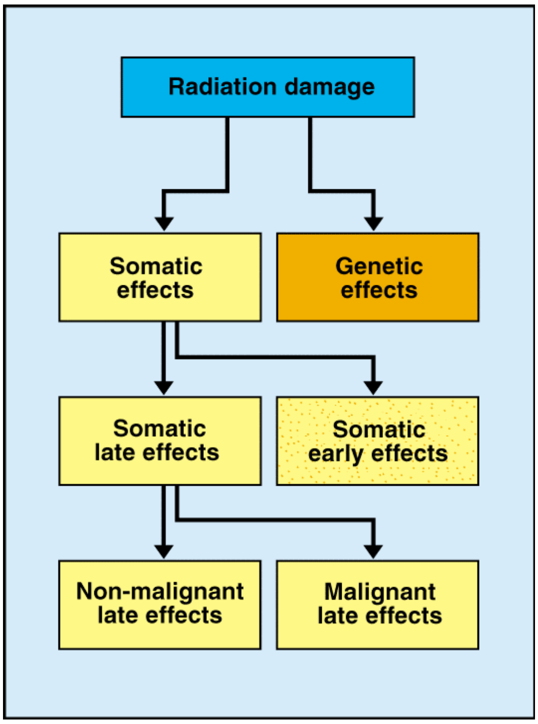
Electromagnetic radiation emitted during the transfer of an electron of the sheath to a further internally situated shell of an atom. The wavelength depends upon the respective element and type of transfer.

Radiation chemistry

Branch of chemistry dealing with the effect of energy-rich radiation (e.g. gamma or neutron radiation) on chemical systems.

Radiation damage in human beings

Radiation exposure may entail somatic and inheritable effects. Somatic effects occur in the persons exposed themselves, inheritable effects can only manifest themselves in descendants. In the case of somatic radiation effects, a distinction is drawn between →stochastic and →deterministic radiation effects.



Classification of radiation damage

Radiation damage, biological

Disadvantageous change in the biological properties due to ionizing radiation.

Radiation damage, early symptoms

Acute radiation damage to human beings is observed only after irradiation with very high doses. The time sequence of the disease symptoms depends on the dose. →radiation effect in the case of very high whole-body irradiation

Radiation damage, physical-chemical

Disadvantageous change in the physical and chemical properties of a material due to ionizing radiation.

Radiation detector

Device or material in which radiation initiates processes suitable for demonstrating or measuring the radiation. →dosimeter, →Geiger-Müller counter, →proportional counter, →scintillation counter

Radiation effect, stochastic

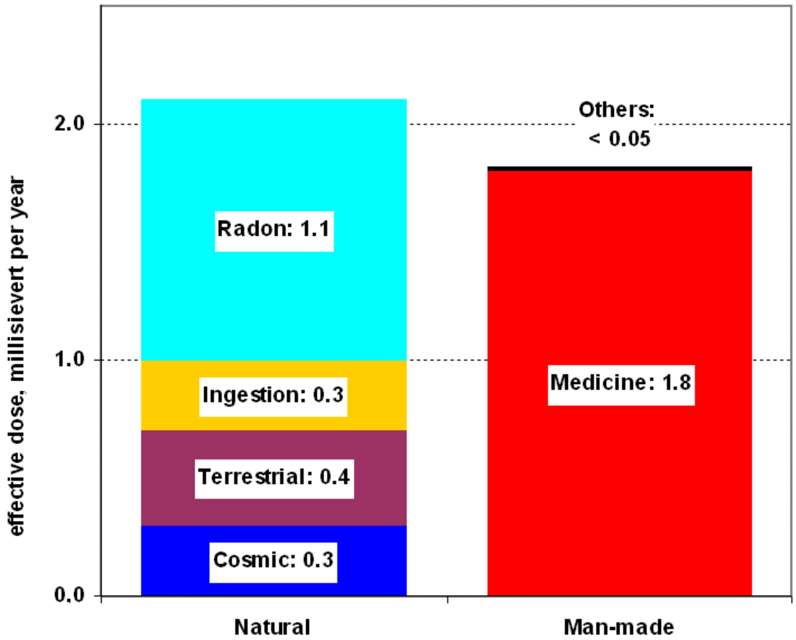
→stochastic radiation effect

Radiation-exposed persons

→persons exposed to radiation in their work

Radiation exposure, average in Germany

The effective dose from all natural and artificial radiation sources amounts for inhabitants in Germany to an average of 3.9 millisievert per year. Natural radiation exposure and medical exposure, particularly x-ray diagnostics, contribute each nearly half of the total dose. Compared to the radiation dose from nature and medicine and above all considering the considerable variation of these dose values, all other dose contributions are actually negligible.



Average radiation exposure in Germany, 2010

Radiation exposure, building material, Germany

The building material used for house building influences the radiation dose of human beings due to natural radioactive substances. The radiation within buildings made of bricks or concrete is higher than in buildings made of wood or some type of pre-assembled units since this building material contains less natural radioactive substances.

Building material	Additional radiation exposure (mSv/year)
Wood	- 0.2* to 0
Chalky sandstone, sandstone	0 to 0.1
Brick, concrete	0.1 to 0.2
Natural stone, technically produced gypsum	0.2 to 0.4
Slag brick, granite	0.4 to 2

Radiation exposure in Germany due to building material, * due to shielding

Radiation exposure, civilization-related, Germany

The majority of civilization-related radiation exposure is caused by medical x-ray applications for diagnostic purposes. Including the dose from nuclear medicine the resulting average effective dose of the population in Germany amounts to 1.8 mSv per year. A further contribution to the radiation dose entails the still existing effects of above-ground nuclear weapon tests. The radiation dose resulting from global fallout in the atmosphere is decreasing since the suspension of the nuclear weapon tests. In the mid-sixties, it amounted to up to 0.2 mSv per year, presently the exposure is less than 0.005 mSv per year. Air traffic contributes about 0.01 mSv per year to the annual effective dose. The additional radiation dose on a flight Frankfurt - New York - Frankfurt amounts to approx. 0.1 mSv. The average dose due to the peaceful use of nuclear energy for the inhabitants in the vicinity of 3 km around a nuclear power plant due to the discharge of radioactive substances with the exhaust air is less than 0.0003 mSv per year. The mean value of the total civilization-related radiation exposure in Germany amounts to about 1.8 mSv annually.

Cause for radiation dose	Effective dose in mSv/year	
	Mean value for the population	Range of values for individual persons
Medicine	1.8	0.01 to 30
Chernobyl accident	0.005	0.001 to 0.02
Nuclear weapon tests	0.005	0.002 to 0.01
Flights	0.01	0.01 to 3
Industrial products	0.001	0.1 to 0,1
Fossil energy power plants	0.001	0.001 to 0.01
Nuclear power plants	0.001	0.001 to 0.01
occupational exposed persons	*0.35*	*0.1 to 20*
Total	1.8	-

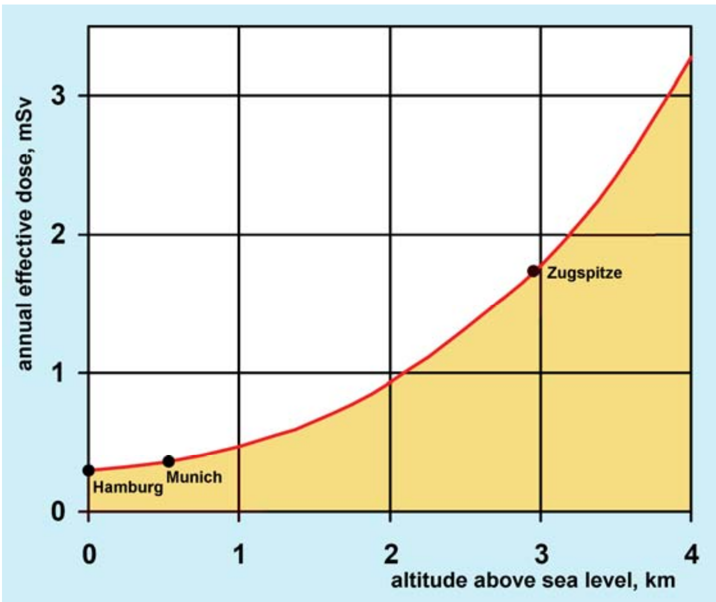
Civilization-related radiation exposure in Germany, 2010

Radiation exposure, comparability, natural/civilization-related

All types of ionising rays cause the same primary physical processes of ionization or excitement of atoms or molecules in the irradiated material. This is independent of whether they are of natural or artificial origin. If the radiation exposures are indicated in sievert, they are directly comparable, irrespective whether natural or artificial, internal or external radiation exposure is involved.

Radiation exposure, cosmic

The radiation reaching the earth from space is mostly of galactic and only partly of solar origin. It is very rich in energy. This primary cosmic radiation mainly consists of protons. Due to different interaction processes in the outer layers of the atmosphere new radiation groups are generated - photons, electrons, positrons, neutrons and myons. The first radiation types form the „soft“ secondary cosmic ray component, the myons the penetrating „hard" secondary cosmic ray component which can even be detected in deep mines. The influence of the magnetic field of the earth on the primary cosmic radiation results in a dependence of the secondary cosmic radiation on the geomagnetic width. The intensity of the cosmic radiation depends extensively on the altitude above sea level, since part of the radiation is absorbed by the atmosphere. Taking all components of cosmic radiation into account, this results in an annual radiation exposure of 0.3 mSv at sea level.



Cosmic radiation exposure as a function of altitude, geogr. latitude 50° north

Radiation exposure, dose limits, Germany

Dose value of an ionizing radiation fixed by the legislator as a maximum to which a person may be exposed based on recommendations from scientific committees. Different dose limit values are fixed for different groups of persons. When handling radioactive substances and ionizing radiation the principle that any unnecessary radiation exposure is to be avoided must be observed and if unavoidable it is to be kept as low as possible, even when within the legal limit values. The German Radiation Protection Ordinance and the X-Ray Ordinance fixes the limit values for occupationally exposed persons as listed in the table. Lower values apply for occupationally exposed pregnant women and apprentices.

Tissue or organ	Limit
Effective dose	20 mSv/year
Organ dose	
Bone marrow (red), gonads, uterus	50mSv/year
Adrenals, bladder, brain, breast, lens of the eye, small intestine, upper large intestine, kidney, liver, lung, muscle, oesophagus, pancreas, spleen, stomach, thymus	150 mSv/year
Bone surface, thyroid	300 mSv/year
Ankles, feet, forearms, hands, skin	500 mSv/year

Dose limits in Germany for occupationally exposed persons

The effective dose for members of the public must not exceed 1 mSv/year. The limit for the lens of the eye is 15 mSv/year and for the skin 50 mSv/year.
Nuclear power plants must not exceed by radioactive emissions with exhaust air or waste water:

Effective dose and dose for gonads, uterus, red bone marrow	0.3 mSv/year
Dose for adrenals, bladder, brain, breast, small intestine, upper large intestine, kidney, liver, lung, muscle, oesophagus, pancreas, spleen, stomach, thyroid, thymus	0.9 mSv/year
Dose for bone surface, skin	1.8 mSv/year

These dose limits shall be observed at the most unfavourable point of effect, taking account of all relevant load paths, the dietary and lifestyle habits of the reference person in addition to any possible prior contamination by other plants and facilities.

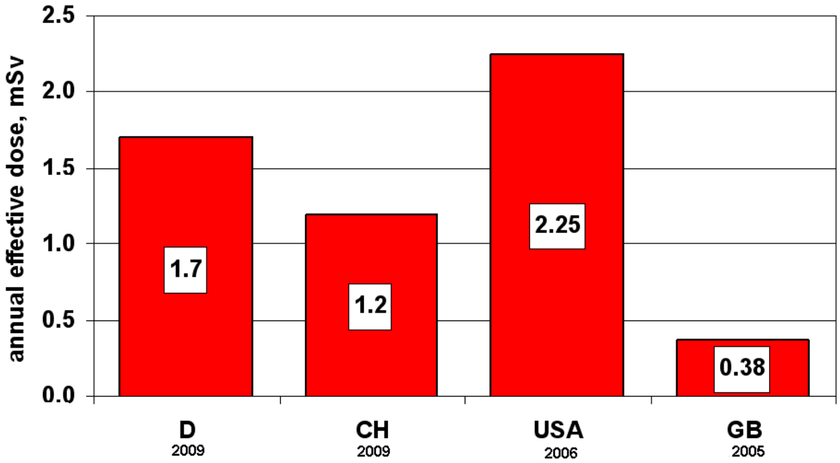
Radiation exposure, medical, Germany

The average effective dose of the population in Germany due to medical application of ionising rays and radioactive substances amounts to 1.8 mSv per year. X-ray diagnostics make up the largest part of civilisation-related radiation exposure of the population in Germany. The frequency of x-ray examinations in Germany amounts to 1.6 examinations per caput per year and the effective dose amounts to 1.7 mSv/a. Although there is a declining trend in some x-ray examinations, which can be explained by the growing use of alternative examination procedures, there is an increase in modern dose-intensive examinations such as computer tomography. Nuclear medicine in Germany contributes about 0.1 mSv per caput per year, considerably less to radiation exposure of the population because of the lower application frequency compared to x-ray diagnostics and the partly lower effective dose per examination.

Type of examination	Effective dose, mSv
CT abdomen	8.8 – 16.4
CT spinal column	4.8 – 8.7
CT thorax	4.2 – 6.7
CT head	1.7 – 2.3
Arteriography	10 - 30
Colon	5 - 12
Stomach	4 - 8

Urinary tract	2 - 5
Lumbar spine	0.6 - 1.1
Pelvis	0.3 - 0.7
Thorax	0.02 - 0,04
Tooth	0.01

Average effective dose for various x-ray examinations, Germany



Average effective dose of population in different countries due to x-ray diagnostics

Radiation exposure, natural

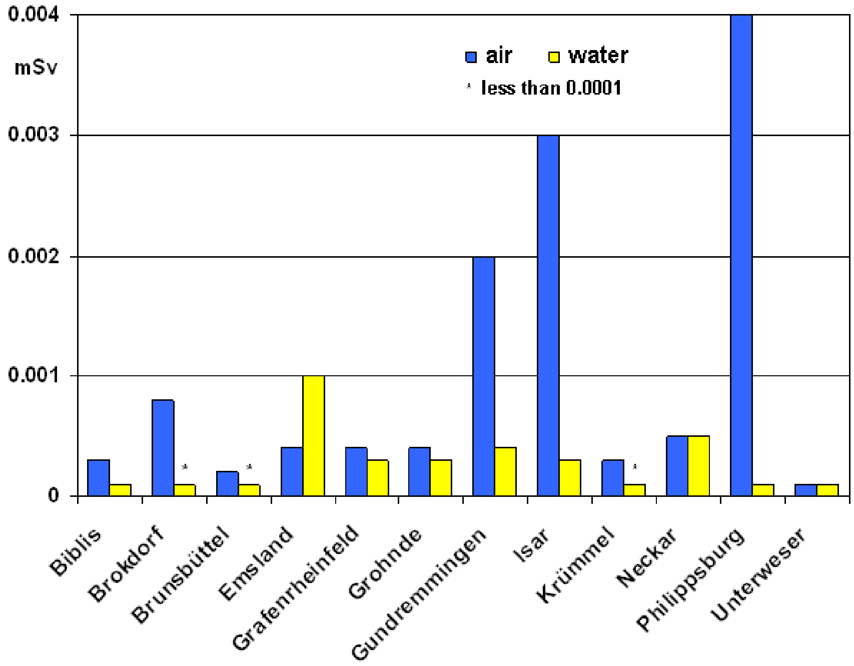
In Germany the natural radiation exposure for most of the inhabitants amounts to 1 to 6 mSv per year with an average value of 2.1 mSv per year. External radiation exposure contributes to one third and internal radiation exposure to two thirds of the effective dose from all natural radiation sources. The dose due to external irradiation comes in equal proportions from cosmic radiation, potassium-40 and nuclides of the uranium and thorium chain. Approximately three quarters of the effective dose due to incorporated radionuclides is made up of radon-222 and radon-220 and in particular their short-lived decay products, followed by potassium-40 and polonium-210.

Exposure by	Annual effective dose in mSv		
	External irradiation	Internal irradiation	Total
Cosmic radiation			
at sea level			
ionizing component	0.23		}0.3
neutrons	0.07		
at 1000 m altitude			
ionizing component	0.29		}0.44
neutrons	0.15		
Cosmogenic radionuclides		0.02	0.02
Primordial radionuclides			
K-40	0.15	0.17	0.3
U-238 chain			
U-238 → Ra-226		0.01	
Rn-222 → Po-214	}0.11	1.10	}1.3
Pb-210 → Po-210		0.12	
Th-232 chain			
Th-232 → Ra-224	}0.14	0.02	}0.2
Rn-220 → Tl-208		0.05	
Total	**0.7**	**1.4**	**2.1**

Contributions of various sources of natural radiation exposure in Germany

Radiation exposure, nuclear power plants, Germany

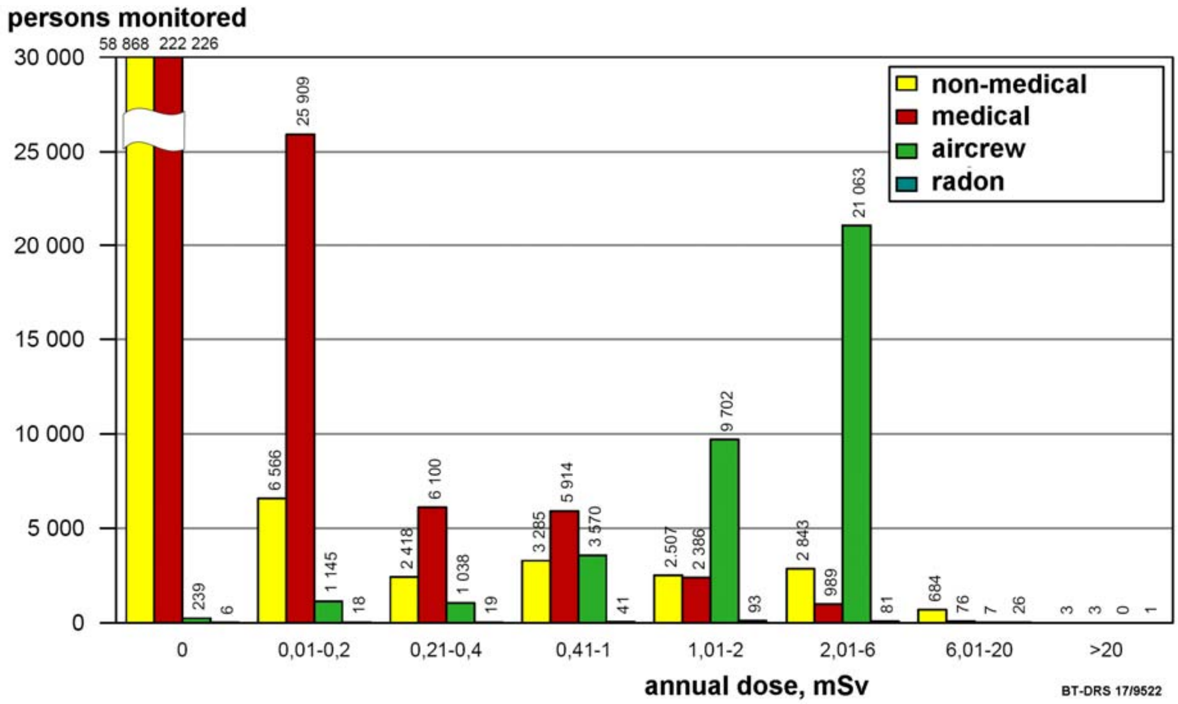
The radiation exposure in the environment of nuclear facilities is determined for the reference person defined in the Radiation Protection Ordinance based on the results of emission control in accordance with the process stipulated in the "General administrative regulation for the determination of radiation exposure by disposal of radioactive substances from nuclear plants or facilities". The calculation of radiation exposure of the population in 2010 in the vicinity of nuclear power plants by the emission of radioactive substances with exhaust air resulted in an effective dose for adults of 0.004 mSv as the highest value for the Nuclear Power Plant Philippsburg; this is 1.5 % of the limit value of the Radiation Protection Ordinance. The highest value of the thyroid gland dose for infants was calculated at 0.007 mSv (less than 1 % of the corresponding dose limit value) for the Nuclear Power Plant Philippsburg.
The highest value of the effective dose for adults from emissions of radioactive substances with the waste water from nuclear power plants amounted to 0.001 mSv (0.3 % of the dose limit value) at the location of the Nuclear Power Plant Emsland.
The radiation exposure at the lower reaches of the rivers has been closer examined with consideration of all emitters. For the mouth of the Neckar, an effective dose of about 0.0008 mSv for adults and of 0.0013 mSv for infants was established; at the lower reaches of Main and Weser 0.0003 mSv for adults and 0.0005 mSv for infants were calculated. On the Rhine and the Danube, the effective doses for adults were around 0.0001 to 0.0004 mSv.



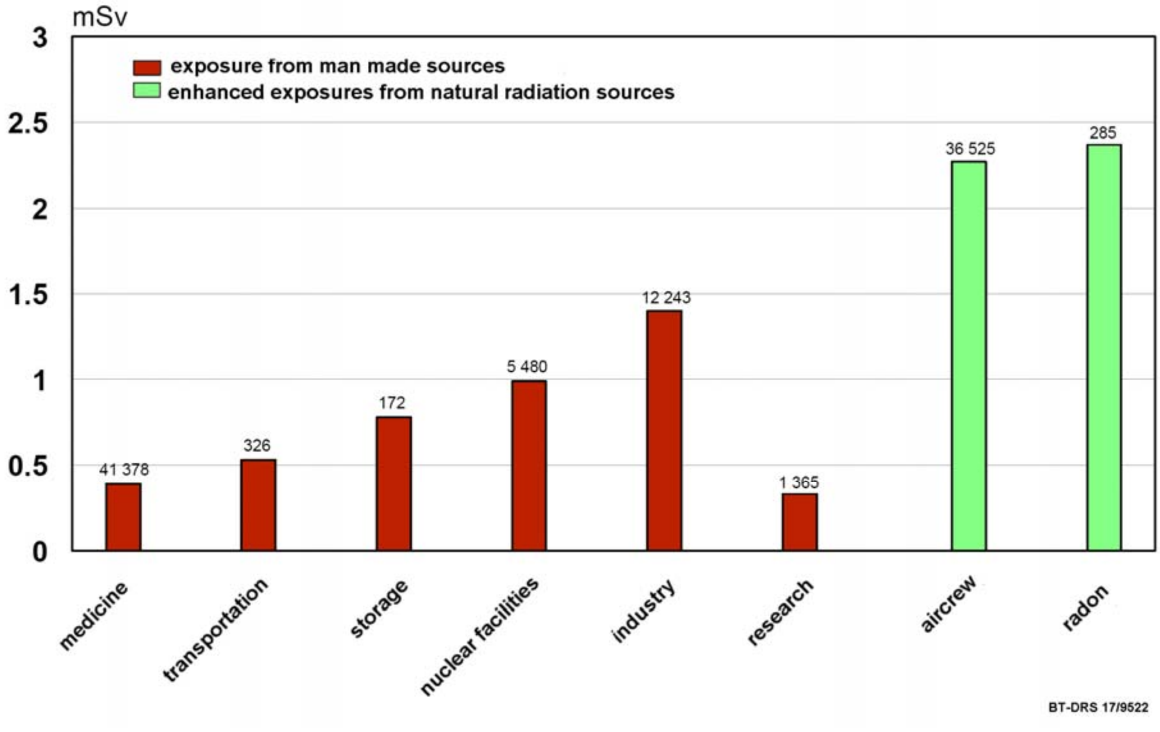
Radiation exposure for adults at the most unfavourable point in the vicinity of nuclear power plants by emission of radioactive substances with exhaust air and waste water, 2010

Radiation exposure, occupational, Germany

In 2010 about 340,000 persons in Germany were monitored with personal dosimeters. 78 % of them worked in the medical sector. The total annual dose of all persons monitored amounted to about 40 man-Sievert. The average annual dose of all persons monitored amounted to 0.12 mSv in 2010. For 84 % of the persons monitored, the values determined were below the smallest determinable dose (0.05 mSv per year). If an average value is calculated only for persons with an annual dose other than zero, an average annual personal dose of 0.67 mSv results for these 59 800 persons. According to the German Radiation Protection Ordinance the radiation exposure of airline personnel due to the higher cosmic radiation exposure flying in high altitudes has to be calculated and registered. The total dose for these 36,800 persons amounted in 2010 to 83 Sv, the calculated average dose is 2.25 mSv.



Annual dose of monitored persons, Germany, 2010



Average annual dose to workers in different working areas, Germany, 2010

Radiation exposure, power plants

Not only nuclear power plants emit radioactive substances with the exhaust air. Fossil fuels contain various concentrations of natural radioactive substances which are released during combustion. Different firing techniques lead to extremely wide variations in enrichment of the flue dust due to the temperature-dependent volatility. For 1 GWa of electric energy generated the emission of long-lived alpha-radiating substances amounts to about 10 GBq for a hard coal and 1 GBq for a lignite-fired power plant. The effective dose equivalent for various power plants occurring at the most unfavourable point of influence is in the range of 0.1 to 5 microsievert per year.

Primary energy carrier	Max. effective dose in the environment μSv per year	Dose-relevant nuclides
Lignite Hard coal Oil	0.5 to 2 1 to 4 1	U-238, Th-232 and decay products, in particular Ra-226, Pb-210, Po-210
Natural gas	0.2 to 1	Radon-222 and decay products
Nuclear power	0.1 to 5	Fission and activation products

Radiation exposure by power plants with various primary energy carriers standardized to the generation of 1 GWa electric energy

Radiation exposure, terrestrial

Terrestrial radiation comes from the natural radioactive substances which exist in various concentrations everywhere on earth. The dose rate resulting from terrestrial radiation depends on the geological formations of the subsoil and therefore varies from one location to another. In Germany, an average external radiation dose of 0.5 mSv per year results due to terrestrial radiation; in some parts of Brazil and India these values are ten times higher.

Area	Average effective dose mSv/year	Max. absorbed dose outdoor mGy/year
Germany	0,4	5
India: Kerala, Madras	4	50
Brazil: Espirito Santo	6	800
Iran: Ramsar	6	850

Radiation dose due to terrestrial radiation in various areas

Radiation hygiene

Findings and measurements to identify and evaluate biological radiation effects in human beings, measures for radiation protection and related technical questions regarding medical and non-medical application of ionizing radiation as well as principles on the indication of ionizing radiation applications.

Radiation medicine

Branch of medicine with the specialist fields of radiation biology, x-ray diagnostics, radiation therapy, nuclear medicine.

Radiation physics

Branch of physics dealing with the properties and physical effects of ionizing rays.

Radiation protection

Radiation protection deals with the protection of individual persons, their descendants and the population as a whole against the effects of ionizing radiation. The aim of radiation protection is to avoid deterministic radiation effects and to limit the probability of stochastic effects to values considered acceptable. An additional task is to ensure that activities entailing radiation exposure are justified.

Radiation protection areas

Radiation protection areas are to be established in the case of activities requiring a permit pursuant to the Radiation Protection Ordinance and X-ray Ordinance. Depending on the level of radiation exposure, a distinction is drawn between monitoring areas, controlled areas and exclusion areas with regard to the external and internal radiation exposure. In compliance with EU regulations, the following values are valid:

- Monitoring areas
  Monitoring areas are in-plant areas which do not belong to the controlled areas and in which persons may receive an effective dose of more than 1 millisievert or organ doses higher than 15 millisievert for the eye lens or 50 millisievert for the skin, hands, forearms, feet and ankles in a calendar year.
- Controlled areas
  In controlled areas persons may receive an effective dose of more than 6 millisievert or organ doses higher than 45 millisievert for the lens of the eye or 150 millisievert for the skin, hands, forearms, feet and ankles in a calendar year.
- Exclusion areas
  Exclusion areas are part of the controlled areas where the local dose rate may be higher than 3 millisievert per hour.

Controlled areas and exclusion areas are to be fenced off and marked permanently and be clearly visible. A residence time of 40 hours per week and 50 weeks in a calendar year is decisive for determination of the controlled area or monitoring area limits if no other substantiated information on the residence time is available.

Radiation protection officer

The party responsible for radiation protection is required to appoint radiation protection officers in compliance with the regulation on radiation protection and the x-ray ordinance insofar as this is necessary for safe operation of the plant and supervision of activities. Radiation protection officers must demonstrate the knowledge required for radiation protection.

Radiation syndrome

Symptoms occurring as a consequence of short-term high radiation exposure of the whole body. →radiation effect in the case of very high whole-body irradiation

Radiation weighting factors

The probability of stochastic radiation effects depends not only on the absorbed dose, but also on the type and energy of the radiation causing the dose. This is considered by weighting the absorbed dose with a factor related to the radiation quality. In the past this factor was known as the quality factor. For photon and electron radiation, the radiation weighting factor has the value 1 independently of the energy of the radiation and for alpha radiation the value 20. For neutron radiation, the value is energy-dependent and amounts to 5 to 20.

Radiation type and energy	Radiation weighting factor w_R
Photons, all energies	1
Electrons, muons, all energies	1
Neutrons	
< 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Protons > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Radiation weighting factor w_R, Euratom basic standards 1996

The numerical values indicated above are valid legal EU-regulations for calculating the equivalent dose in an organ or tissue. In 2007 ICRP published a new set of radiation weighting factors (ICRP Publ. 103: The 2007 Recommendations of the International Commission on Radiological Protection) given below. These data are adopted in the proposal of the new EU Basic Safety Standards (European Commission, Proposal for a

Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, COM(2012) 242 final 2012-05-30 to be accepted by the Council of the European Union *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0242:FIN:EN:PDF*

Radiation type	Radiation weighting factor w_R
Photons, all energies	1
Electrons, muons, all energies	1
Protons and charged pion	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (see equation)

Radiation weighting factors, ICRP 2007

$$w_R = \begin{cases} 2.5 + 18.2e^{-[\ln (E_n)]^2/6}, & E_n < 1 \text{ MeV} \\ 5.0 + 17.0e^{-[\ln (2E_n)]^2/6}, & 1 \text{ MeV} \leqslant E_n \leqslant 50 \text{ MeV} \\ 2.5 + 3.25e^{-[\ln (0.04E_n)]^2/6}, & E_n > 50 \text{ MeV} \end{cases}$$

Continuous function in neutron energy, E_n (MeV),
for the calculation of radiation weighting factors for neutrons

Radio diagnostics

Branch of radiology dealing with x-ray examinations, i.e. radiograms and radioscopy for diagnostic purposes.

Radio iodine

Radioactive isotope of iodine.

Radioactive isotope

Synonym for →radionuclide.

Radioactive substances

Radioactive substances within the meaning of the Atomic Energy Act are:

- nuclear fuels, i.e.
  a) plutonium 239 and plutonium 241,
  b) uranium enriched with the isotopes 235 or 233,
  c) any substance containing one or several of the substances mentioned in a) and b),
  d) substances which can be used in a suitable plant to maintain a chain reaction which initiates its own repetition and which are determined in an ordinance having the force of law.
- other radioactive substances which - without being nuclear fuel -,
  a) spontaneously emit ionizing rays,
  b) contain one or several of the substances mentioned in a) or are contaminated with such substances.

The Radiation Protection Ordinance further distinguishes:

- enclosed radioactive substances: radioactive substances which are enclosed by a tight, firm, inactive shell or permanently embedded in solid inactive substances so that the release of radioactive substances is prevented in the case of usual normal stress; a dimension must at least amount to 0.2 cm;
- open radioactive substances: all radioactive substances except for enclosed radioactive substances;

- short-lived radionuclides: radioactive substances with a half-life of up to 100 days;
- long-lived radionuclides: radioactive substances with a half-life of more than 100 days.

Radioactivity

Property of certain substances to convert without external effect, emitting a characteristic radiation. Radioactivity was discovered for uranium by Becquerel in 1896. If the substances, or to be more precise, the radionuclides occur in nature, one refers to natural radioactivity; if they are a product of nuclear conversions in nuclear reactors or accelerators, one refers to artificial radioactivity. More than 2 750 radionuclides are known today. Each radionuclide is characterized by its →half-life, the time during which half the atomic nuclei convert in a given quantity. Half-lives of several billion years (uranium-238; even still longer-lived is tellurium-128 with a half-life of $7.2 \cdot 10^{24}$ years) to the millionth of a second (Po-212) are known. The radiation emitted during decay and its energy is also characteristic. For example, radium-226 decays emitting alpha radiation, while iodine-131 emits beta rays.

Radioactivity, induced

Radioactivity generated by irradiation, e.g. with neutrons.

Radioactivity, natural

Naturally occurring nuclides which are radioactive. A distinction is drawn between natural radionuclides which are continuously regenerated by nuclear reactions of cosmic radiation, cosmogenic radionuclides (→radionuclides, cosmogenic) and primordial (initial) radionuclides (→radionuclides, primordial), which have existed since the earth was formed and due to their long half-life have not yet decayed and the radionuclides generated from the primordial radionuclides U-238, U-235 and Th-232 of the associated →decay chain.

Nuclide	Activity in Bq
H-3	25
Be-7	25
C-14	3800
K-40	4200
Rb-87	650
U-238, Th-234, Pa-234m, U-234	4
Th-230	0.4
Ra-226	1
short-lived Rn-222 decay products	15
Pb-210, Bi-210, Po-210	60
Th-232	0.1
Ra-228, Ac-228, Th-228, Ra-224	1.5
short-lived Rn-220 decay products	30

Natural radioactive substances in the human body

Radiocarbon

→carbon-14

Radiochemistry

Branch of chemistry dealing with reactions, synthesis and analysis where the reaction partners are radioactive. →nuclear chemistry

Radioecology

Radioecology analyses the behaviour and the effect of radioactive substances in the biosphere. It comprises production and release, transport through the abiotic part of the biosphere, food chains, intake and distribution in humans and the effect of radiation on living organisms.

Radio-element

An element without stable isotopes. The term should not be used in the meaning „radionuclide“.

Radiogram

Representation of the living human or animal body or an object using x-rays to render constitution, condition or functions visible for subsequent viewing.

Radiography

Application of penetrating ionizing radiation to examine materials. The radiation blackens a film arranged behind the material sample penetrated by radiation. The differences in blackening suggest flaws and unevenness in the material.

Radioisotope generator

System which directly converts the heat released during radioactive decay into electricity. Such generators function with thermoelectric or thermionic converters. Application e.g. as an energy source for space missions far from the sun.

Radiology

In the wider sense „the medical study of radiation“, consisting of theoretical radiology (radiation biology, medical radiation physics) and clinical radiology. Radiology in the narrower sense comprises x-ray diagnostics and radiation therapy.

Radiolysis

Dissociation of molecules by radiation. Example: water dissociates under radiation into hydrogen and nitrogen.

Radionuclide

Instable nuclide spontaneously decaying without external effect under radiation emission. More than 2 750 natural and artificial radionuclides are known.

Radionuclides, cosmogenic

Radionuclides generated by interaction of cosmic radiation with the atomic nuclei of the atmosphere or with extraterrestrial matter coming down to earth as meteors or meteorites.

Nuclide	Half-life	Nuclide	Half-life	Nuclide	Half-life
H-3	12,323 a	Si-32	172 a	Mn-53	$3{,}7 \cdot 10^6$ a
Be-7	53,3 d	P-32	14,3 d	Mn-54	312 d
Be-10	$1{,}6 \cdot 10^6$ a	S-35	87,5 d	Fe-55	2,73 a
C-14	5730 a	S-38	2,8 h	Fe-60	$1{,}5 \cdot 10^6$ a
Na-22	2,60 a	Cl-36	$3{,}0 \cdot 10^5$ a	Co-60	5,27 a
Na-24	15 h	Ar-39	269 a	Ni-59	$7{,}5 \cdot 10^4$ a
Al-26	$7{,}2 \cdot 10^5$ a	Ar-42	33 a	Ni-63	100 a
Mg-28	20,9 h	Ca-41	$1{,}0 \cdot 10^5$ a	Kr-85	10,7 a
Si-31	2,6 h	Ti-44	60,4 a	I-129	$1{,}6\ 10^7$ a

Cosmogenic radionuclides

Radionuclides, primordial

Initial radionuclides existing since the earth was formed and which have not completely decayed due to their long half-life in addition to the radionuclides generated from the primordial radionuclides U-238, U-235 and Th-232 of the associated →decay chain.

Nuclide	Half-life years	Nuclide	Half-life years
K-40	$1.3 \cdot 10^{9}$	La-138	$1.1 \cdot 10^{11}$
V-50	$1.4 \cdot 10^{17}$	Nd-144	$2.3 \cdot 10^{15}$
Ge-76	$1.5 \cdot 10^{21}$	Nd-150	$1.7 \cdot 10^{19}$
Se-82	$1.0 \cdot 10^{20}$	Sm-147	$1.1 \cdot 10^{11}$
Rb-87	$4.8 \cdot 10^{10}$	Sm-148	$7.0 \cdot 10^{15}$
Zr-96	$3.9 \cdot 10^{19}$	Gd-152	$1.1 \cdot 10^{14}$
Mo-100	$1.2 \cdot 10^{19}$	Lu-176	$2.6 \cdot 10^{10}$
Cd-113	$9.0 \cdot 10^{15}$	Hf-174	$2.0 \cdot 10^{15}$
Cd-119	$2.6 \cdot 10^{19}$	Ta-180	$1.2 \cdot 10^{15}$
In-115	$4.4 \cdot 10^{14}$	Re-187	$5.0 \cdot 10^{10}$
Te-123	$1.2 \cdot 10^{13}$	Os-186	$2.0 \cdot 10^{15}$
Te-128	$7.2 \cdot 10^{24}$	Pt-190	$6.5 \cdot 10^{11}$
Te-130	$2.7 \cdot 10^{21}$	Bi-209	$1.9 \cdot 10^{19}$

Primordial radionuclides outside of decay chains

Radio-photoluminescence

Property of certain substances to form fluorescence centres when irradiated with ionizing radiation which emit light in another spectral region when excited with ultraviolet light. In the case of suitable material the emitted light intensity is proportional to the number of luminous centres and thus to the incident dose. →phosphate glass dosimeter.

Radioscopy

Transillumination of the living human or animal body or an object using x-rays to render constitution, condition or functions visible for immediate viewing.

Radiotherapy

Radiation treatment. In a stricter sense, any treatment of human beings with ionizing radiation is meant. Numerous radiation treatments are carried out in the case of cancer.

Radiation effect in the case of very high whole-body irradiation

Effects to be expected for short-term whole-body irradiation:

- up to 0.5 Gy: no verifiable effect except for slight changes in the complete blood count;
- 0.5 to 1 Gy: for 5 to 10% of the persons exposed, vomiting, nausea and fatigue for about one day;
- 1 to 1.5 Gy: for about 25% of the persons exposed, vomiting and nausea, followed by other symptoms of radiation syndrome; no deaths to be expected;
- 1.5 to 2.5 Gy: for about 25% of the persons exposed, vomiting and nausea, followed by other symptoms of radiation syndrome; some deaths possible;
- 2.5 to 3.5 Gy: for almost all persons exposed, vomiting and nausea on the first day, followed by other symptoms of radiation syndrome; about 20% of deaths within 2 to 6 weeks after exposure; about 3 months convalescence for survivors;
- 3.5 to 5 Gy: for all persons exposed, vomiting and nausea on the first day, followed by other symptoms of radiation syndrome; about 50% of deaths within one month; about 6 months convalescence for survivors;

- 5 to 7.5 Gy: for all persons exposed, vomiting and nausea within 4 hours after exposure, followed by other symptoms of radiation syndrome. Up to 100% deaths; few survivors with about 6 months convalescence;
- 10 Gy: for all persons exposed, vomiting and nausea within 1 to 2 hours; probably no survivors;
- 50 Gy: extremely serious illness occurring almost immediately; death of all persons exposed within one week.

Radiotoxicity

Measure of the nocuousness to health of a radionuclide. The type and energy of rays, absorption in the organism, residence time in the body, etc. influence the degree of radiotoxicity of a radionuclide.

Radium

Radioactive element with the atomic number 88. Radium occurs naturally together with uranium which decays to radium via a chain of alpha and beta emissions.

Radon

Due to the very long half-lives, the earth's crust contains since its formation among other substances the radionuclides uranium-238, uranium-235 and thorium-232. These convert via a chain of radioactive intermediate products with quite different half-lives to stable lead as the final product. These intermediate products include three radon nuclides: radon-222 (half-life 3.8 days) is generated as a decay product of radium-226, which results from the radioactive decay of uranium-238. In the decay chain of thorium-232, radon-220 (half-life 54 s) occurs and in the decay chain of U-235, radon-219 (half-life 3.96 s). Radon is released wherever uranium and thorium are present in the ground and enters the atmosphere or houses. The radium concentration of the ground and its permeability for this radioactive noble gas is decisive for the radon concentration in the air. Apart from the regional variations, the radon concentration in the atmosphere close to the ground is also subject to seasonal and climatic variations. In buildings, the radon concentration depends essentially on the structural circumstances. In Germany, the annual average value of the radon concentration in the air close to the ground is 15 Bq/m^3 and in buildings 60 Bq/m^3. Radon concentrations greater than 200 Bq/m^3 in ground floor living rooms are not uncommon. Regarding the radiation exposure of people, it is not the radon itself that is important, but the short-lived decay products. These enter the respiratory tract with breathed in air and may reach radiation-sensitive cells with its energy-rich alpha radiation. The short-lived decay products of radon, with 1.4 millisievert per year, account for more than half the total effective dose by natural radiation sources.

Range, medium free

The medium length of a path covered by a particle (photon, atom or molecule) between subsequent impacts.

Rasmussen report

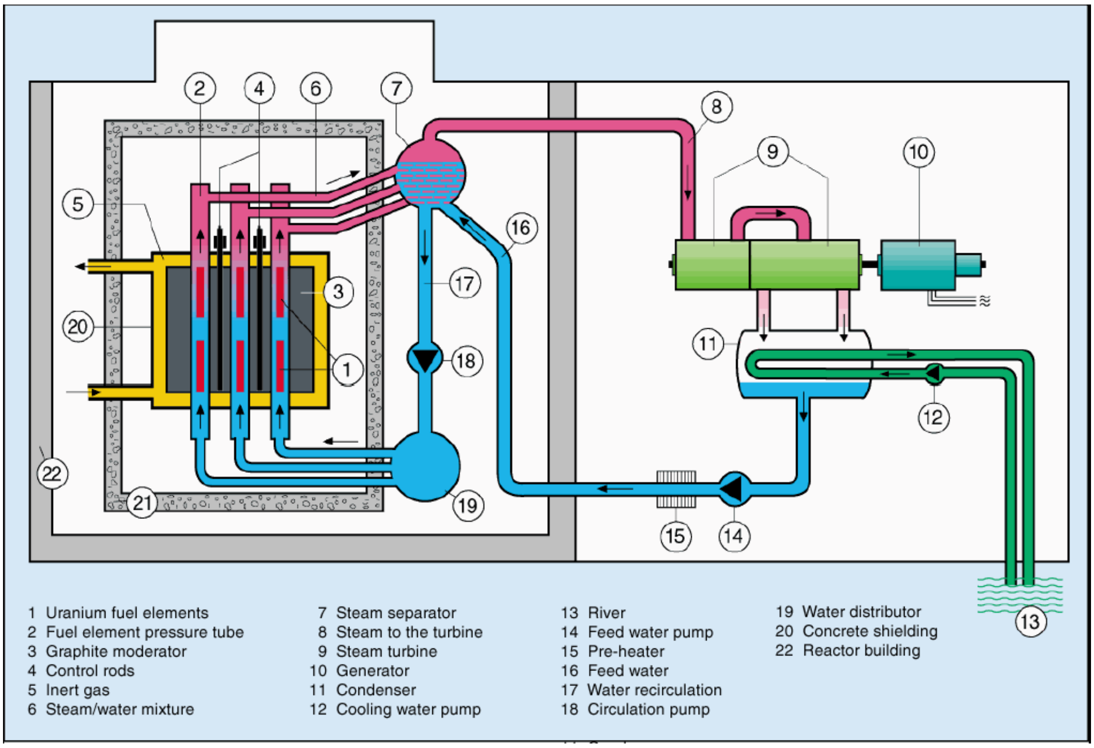
Reactor safety study (WASH-1400) named after the leader of the working group that prepared the study in the USA. →risk study

Ratemeter

Device for the indication of the pulse rate of a counting apparatus present in the time average.

RBMK

Latin transcription of a Russian reactor type designation: Реактор Большой Мощности Канальный (reaktor balschoi moschnosti kanalnui, (reactor of high power of the channel type). RBMK (aka LWGR, Light-Water-Cooled, Graphite-Moderated Reactor) is a graphite-moderated boiling water pressure tube reactor in which the steam is not generated in a pressure vessel, but in up to 2 000 separate pressure tubes containing the fuel elements. The use of graphite as a moderator leads to a large-volume reactor core of 12 m diameter and 7 m height. Consequently, the control of the reactor is relatively complicated from the neutron physical point of view and imposes increased requirements on the mode of operation concerning the control rods. In Russia eleven RBMK units with 1 000 MWe each and four with 12 MWe each are in operation.



Nuclear power plant with RBMK

RBW

→relative biological effect

rd

Symbol for energy unit. →rad

RDB

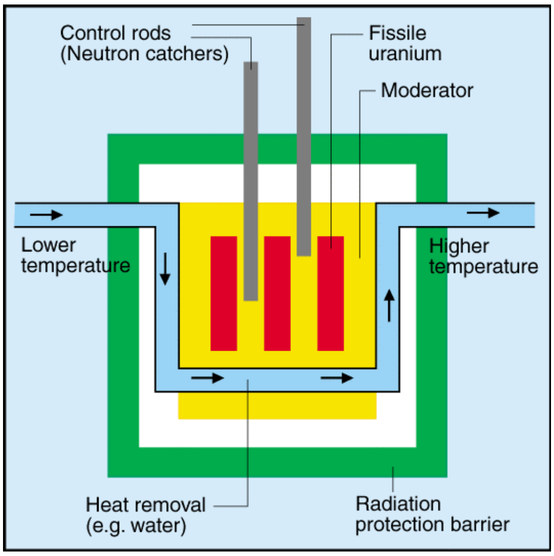
→reactor pressure vessel

Reactivity

Measure of the deviation of a reactor from critical condition. Corresponds to the multiplication factor reduced by 1 and is thus equal to zero in the critical condition. If reactivity is positive, the reactor output increases. In the case of negative reactivity the output level decreases.

Reactor

System used to initiate, maintain and control a fission chain reaction (chain reaction). The main part is a core with fissile →nuclear fuel. In general, a reactor is equipped with a →moderator, a shield and control devices. Reactors are built for research or power generation purposes. Reactors where the chain reaction is maintained by thermal neutrons (→neutrons, thermal) are called thermal reactors; if the chain reaction is maintained by fast neutrons, one refers to fast reactors. The first reactor was put into operation on 2nd December 1942 by a group of researchers headed by Fermi. →pressurized water reactor, →boiling water reactor



Reactor structure, principle

Reactor coolant

Coolant used to remove heat from the reactor core. →secondary coolant

Reactor coolant circuit

Circulation system for the →reactor coolant.

Reactor control

Adjustment of →reactivity to reach or maintain a desired operating condition.

Reactor, fast

Reactor where the fissions are mostly initiated by fast neutrons. A fast reactor has no moderator in contrast to a thermal reactor.

Reactor, gas-cooled

Nuclear reactor with gas as a coolant (carbon dioxide, helium). The AGR facilities in Great Britain are cooled with carbon dioxide, for example.

Reactor pressure vessel

Thick-walled cylindrical steel vessel enclosing the reactor core in a nuclear power plant. The vessel is made of special fine-grained steel, well suited for welding and with a high toughness while showing low porosity under neutron irradiation. The inside is lined with austenitic cladding to protect against corrosion. For a 1 300 MWe pressurized water reactor, the pressure vessel is about 12 m high, the inner diameter is 5 m, and the wall of the cylindrical shell is about 250 mm thick. The overall weight amounts to approx. 530 t without internals. The vessel is designed for a pressure of 17.5 MPa (175 bar) and a temperature of 350 °C.

Reactor protection system

A system receiving information from different measuring facilities which monitor the operational variables essential for the safety of a nuclear reactor. The system is able to automatically initiate one or several safety measures to keep the condition of the reactor within safe limits.

Reactor risk study

→risk study

Reactor Safety Commission, Germany

The Reactor Safety Commission (RSK - Reaktorsicherheitskommission) advises the Federal Ministry for the Environment, Nature Conservation and Reactor Safety in matters of safety and related matters of safety regarding nuclear facilities and disposal of radioactive waste. As a rule the Reactor Safety Commission is made up of twelve members representing the technical fields required for the expert consulting of the Federal Ministry in the mentioned subjects. The members must guarantee expert and objective consultancy for the Federal Ministry. To ensure a balanced consultancy, the members of the Reactor Safety Commission should represent the overall range of opinions justifiable in accordance with the state of science and technology. Membership of the Reactor Safety Commission is a personal honorary position. The members of the commission are independent and not bound by instructions. As a result of its deliberations, the commission decides on scientific and technical recommendations or comments for the Federal Ministry. The commission does not make any legal assessments. The state authorities are informed of the recommendations or comments submitted to the Federal Ministry, which are also made available to the public upon request.

Reactor time constant

The time during which the neutron flux density in a reactor changes by the factor e = 2.718 (e: basis of natural logarithms), when the neutron flux density increases or decreases exponentially.

Reactor types, world-wide

As of Jan 1, 2013, 437 nuclear power plants were in operation and 64 under construction world-wide. Most of the nuclear power plants were equipped with light water reactors, i.e.→pressurized water reactors and →boiling water reactors.

Reactor type	In operation		Under construction	
	Number	Electr. output MW	Number	Electr. output MW
AGR, GGR	15	8.055	-	-
BWR	84	77,737	4	5,250
CANDU/D_2O-PWR	49	24,836	5	3,212
FBR	2	580	2	1,259
PWR	272	250,335	52	51,294
RBMK	15	10,219	1	915
total	**437**	**371,762**	**64**	**61,930**

Nuclear power plants of the world according to reactor types, Jan 1, 2013

Reactor, thermal

Nuclear reactor where the fission chain reaction is maintained by thermal neutrons. Most of the existing reactors are designed as thermal reactors.

Receiving point

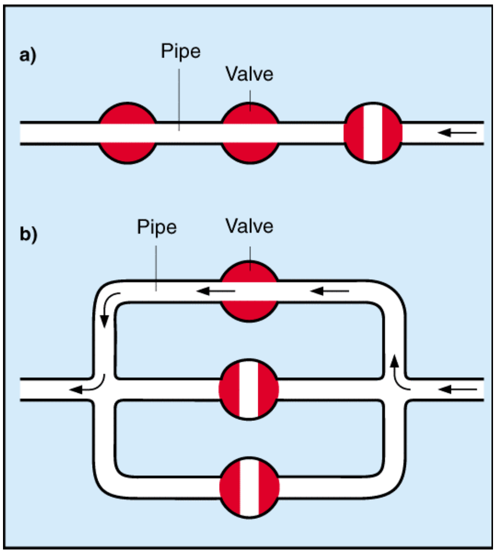
The geographical point at which the effluent plume from a stack reaches the ground depending on meteorological data. The receiving point plays a role in the determination of radiation exposure via the exhaust air path.

Recording threshold

Value of dose equivalent or activity supply where the result of the measurement must be recorded and kept when this value is exceeded.

Redundancy

In information theory, a designation for the existence of superfluous elements in a message, which do not supply additional information, but only support the intended basic information. In reactor technology, all safety-relevant measuring values, e.g. the neutron flux density in the reactor are determined by three measuring systems which are independent from one another and only the value indicated by at least two systems is considered correct. The multiple design of important technical systems (emergency cooling system, emergency power devices) is also called redundancy.



Schematic diagram of redundancy for the closing function (a) and opening function (b) of valves in a pipe

Reference nuclide

For shielding calculations, dispersion calculations or to determine local dose rates, it is often sufficient to consider only a few special radionuclides, the leader nuclides. The latter have a chemical similarity and/or such a high specific decay energy that they override the effects of lower radiating radionuclides. The fact that they are disregarded in calculation therefore does not entail an error in the radiation protection calculations. Reference nuclides are also used to calculate the quantity of other nuclides in the case of known history of the material containing the nuclide(s).

Reference threshold

Value of a variable of the body dose, activity intake or contamination which, when exceeded, requires certain actions and measures.

Reflector

Material layer immediately around the core of a nuclear reactor. The reflector scatters neutrons, which otherwise would escape, back to the core. The reflected neutrons in turn can initiate fissions and therefore improve the neutron balance of the reactor.

Relative biological effect

For a specific living organism or part of an organism, the ratio of the absorbed dose of a reference radiation (mostly 200 kV x-rays) causing a certain biological effect to the absorbed dose of the respective radiation causing the same biological effect. The term should be used exclusively in radiobiology and not in radiation protection.

rem

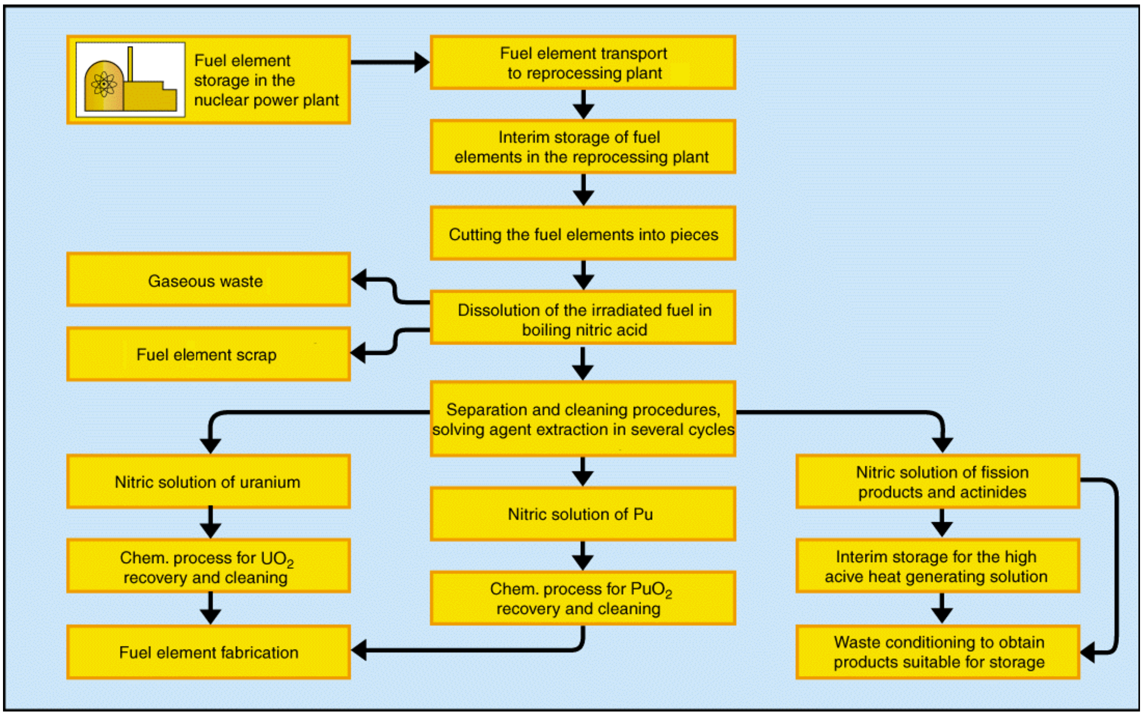
Former unit of dose equivalent, symbol: rem. For radiation protection purposes, the radiation dose was frequently indicated in millirem (mrem). 1 rem = 1 000 mrem. The new unit of the dose equivalent is joule divided by kilogram with the specific unit name →sievert. 1 rem = 1/100 Sv.

Reprocessing Plant Karlsruhe

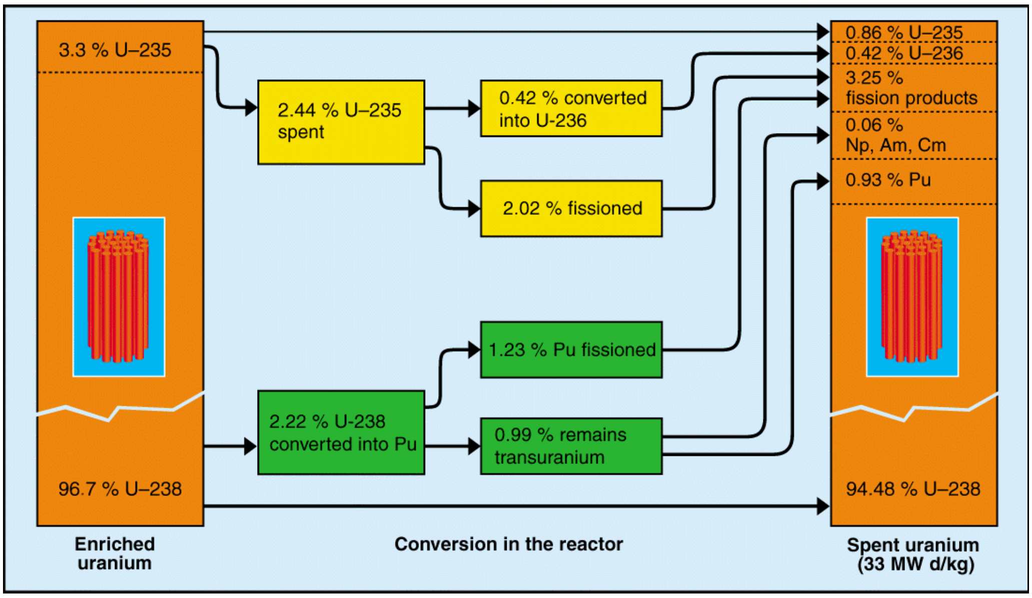
The Reprocessing Plant Karlsruhe (WAK - Wiederaufarbeitungsanlage Karlsruhe) was designed for a throughput of a maximum of 35 t uranium at 200 days of operation per year with an enrichment of up to 3% U-235 equivalent. The disintegration of the fuel elements was effected in the →chop-leach process, the U/Pu separation in the dual-cyclical →PUREX process with 30% TBP in n-dodecane. Since the commissioning of the plant in 1971, about 200 t irradiated fuel was reprocessed and more than 1 t plutonium separated until the end of the operation in 1990. The total plutonium separated in this plant is equal to an energy content of 1.5 million t hard coal at a fissile share of 70%. The high active liquid waste of 60 m^3 which resulted during the reprocessing is stored on the premises of the WAK. The →Vitrification Plant Karlsruhe on the premises of the WAK is ready for solidification of the waste in order to obtain a product suitable for ultimate disposal. The dismantling work of the WAK began in 1996.

Reprocessing

Application of chemical processes to separate the valuable substances - the still existing uranium and the newly generated fissile material plutonium - from the fission products, the radioactive waste in the spent nuclear fuel after its use in the reactor. The →PUREX process for reprocessing underwent several years of large-scale trial. A spent fuel element has, apart form the structure material, approximately the following composition: 96% uranium, 3% fission products (waste), 1% plutonium and small shares of →transuranium elements. The recovered uranium and the plutonium can be reused as fuel in a nuclear power plant following corresponding chemical treatment. The nuclear fuel recoverable in a reprocessing plant with an annual throughput of 350 t corresponds in the case of use in the today common light water reactors to an energy quantity of approx. 10 million t hard coal. In the reprocessing the high active waste (fission products) is separated and by →vitrification brought into a form ensuring safe ultimate disposal.



Scheme of the reprocessing of irradiated fuel elements



Composition of nuclear fuel for light water reactors prior and after the use in a reactor

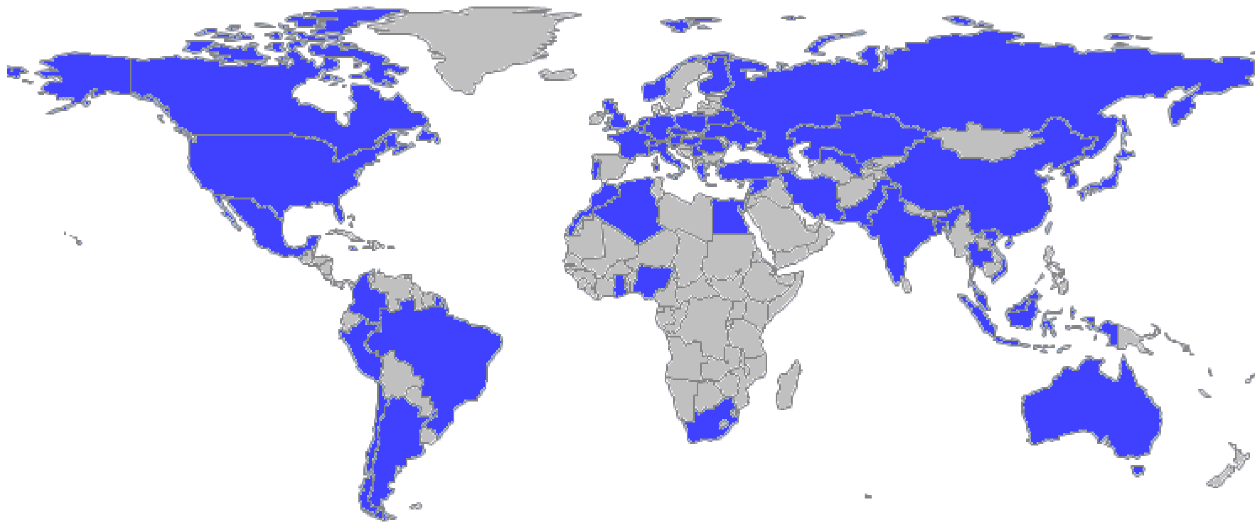
Reprocessing plants, world-wide

Country	Location	Capacity t U / a	Commissioning or operating period
B	Mol	60	1966-1974
D	Karlsruhe	35	1971-1990
F	Marcoule, UP 1	600	1958-1997
F	La Hague, UP 2	800	1966-1974
F	La Hague, UP 2-400	400	1976-2003
F	La Hague, UP 2-800	1,000	1996
F	La Hague, UP 3	1,000	1990
GB	Windscale	300/750	1951-1964
GB	Sellafield, Magnox	1,500	1964
GB	Dounreay	8	1980-1998
GB	Sellafield, THORP	900	1994
IND	Trombay	60	1965
IND	Tarapur	100	1982
IND	Kalpakkam	100	1998
J	Tokai Mura	90	1977-2006
J	Rokkashomura	800	2006 2007
RUS	Mayak B *	400	1948-196?
RUS	Tscheljabinsk	400	1971
RUS	Krasnojarsk	800	
USA	Hanford, T-Plant *		1945-1956
USA	Hanford, B-Plant *	1 t/d	1945-1957
USA	Hanford, REDOX *	15 t/d	1952-1967
USA	Hanford, PUREX *	2,400	1956-1972/1983-1988
USA	Savannah River Site *	~ 3,000	1952-2002
USA	West Valley	300	1966-1972

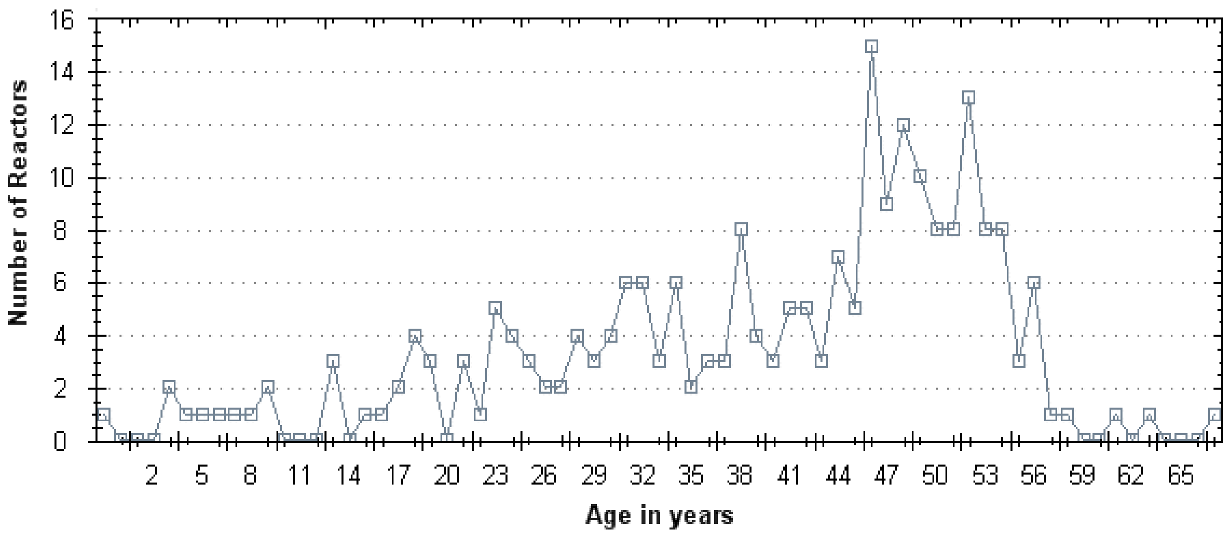
Reprocessing plants, world-wide, * only military use

Research reactor

A nuclear reactor designed mainly for generation of high neutron intensities for research purposes, may also be used for training, material testing and generation of radionuclides. As of January 2013, the International Atomic Agency's Research Reactor Database *http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?filter=0* contains information on research reactors, of which 229 are operational, 130 are shutdown, 316 have been decommissioned and 8 are planned or under construction.



Research reactors in operation, IAEA, January 2013



Age distribution of research reactors, IAEA, January 2013

Residual heat

Heat generated by the decay of radioactive fission products in a nuclear reactor after shutdown - termination of the chain reaction. The residual heat in the first seconds after shutdown amounts to about 5% of the power prior to shutdown. The residual heat in the fuel elements is equal to approx. 2 kW per tonne nuclear fuel after three years of decay time, i.e. about 1 kW per fuel element of a pressurized water reactor.

Residual risk

Remaining risk which cannot be defined in more detail after elimination or inclusion of all conceivable quantified risks in a risk consideration.

Rest-energy

Based on relativity theory, it is concluded that an equivalence relation exists between mass and energy. The energy is equal to the product of mass and the square of light velocity: $E = mc^2$. The rest energy E_0 is also the energy equivalent of a resting, i.e. immobile particle. Therefore, the rest energy of a proton for example is 938.257 MeV. The rest energy of 1 g mass is about $2.5 \cdot 10^7$ kWh.

Rest mass

The mass of a particle at rest. According to the theory of relativity, the mass depends on velocity and increases with growing particle speed. If m_0 is the rest mass, v the particle velocity and c the light velocity, the mass m depending on velocity is calculated as follows:

$$m = \frac{m_0}{\sqrt{1 - (v/c)^2}}$$

Risk

In risk comparisons in particular, a risk is frequently defined as multiplication of the extent of damage (which consequences?) by the frequency of occurrence (how often does the incident occur?). A technology with frequently occurring accidents, but limited consequences (e.g. car) may present higher risks than a technology with rare, but serious accidents (aircraft). This risk variable is the benchmark for assessment of possible consequences of a technology and for comparison of consequences of various technologies.

Risk study

In the Federal Republic of Germany - following corresponding studies in the USA - an own comprehensive study designed to evaluate the risk from nuclear power plants has been prepared. The study was aimed at determining the risk involved in incidents and accidents in nuclear power plants, taking account of German conditions. The first phase was completed in August 1979. Initial risk investigations mainly aimed at assessing the risk involved in accidents in nuclear power plants and comparing it with other risks of civilization and nature. In phase B of the German risk study, extensive research into the incident behaviour was carried out. In this context, the time sequence of the incidents, the impact involved and the intervention of the safety systems provided to control the accident or incident were thoroughly analysed. These investigations showed the importance of in-plant accident management. The analyses demonstrated that in many cases nuclear power plants still have safety reserves when the safety systems do not intervene as intended and safety-related design limits are exceeded. These safety reserves can be used for in-plant accident management to further reduce the risk resulting from accidents. Risk analyses are suitable to identify in-plant accident management and to show how far they can reduce the risk involved in accidents. Investigations on in-plant accident management occupy a central position in the work during phase B of the study. The „German Risk Study on Nuclear Power Plants Phase B“ was published by the GRS (Company for Industrial Plants and Nuclear Safety) in June 1989.

roentgen

Former unit of →ion dose, symbol: R. The ion dose of 1 roentgen is equal to the generation of an electrostatic charge unit by gamma or x-radiation in 1 cm^3 dry air under normal conditions (1.293 mg air). The new unit of the ion dose is coulomb divided by kilogram (C/kg). 1 R = 258 µC/kg; 1 C/kg ≙ 3 876 R.

Rupture protection

Design concept which was not realized to prevent the pressure vessel from bursting by surrounding the reactor pressure vessel with a reinforced concrete shell. The disadvantage of the rupture protection is that inservice inspections of the pressure vessel (e.g. ultrasonic measuring methods) are practically impossible.

S

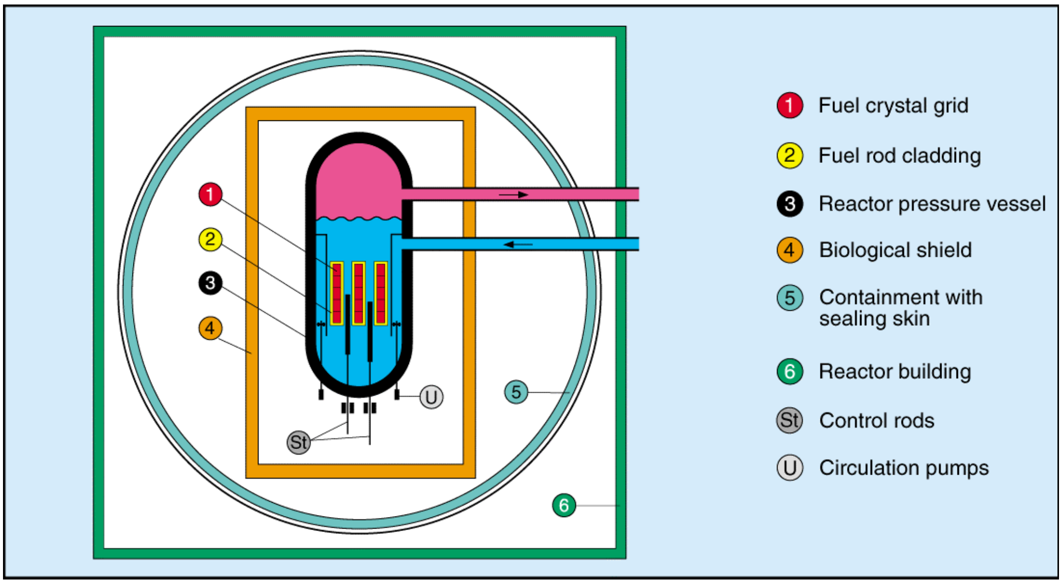
Safeguard

Measures for nuclear material monitoring. These are essentially measures of balance accounting, enclosure, containment and observational monitoring. The measures must ensure individually or in combination timely detection of a fissile material's deviation from the process.

Safety barriers

The safe enclosure of the radioactive inventory of a nuclear facility is effected according to the multiple barrier principle, i.e., to release radioactive substances, these must pass different barriers connected in series. The barriers of a nuclear reactor are e.g.:

- Retention of fission products in the nuclear fuel itself,
- Enclosure of the nuclear fuel in cladding tubes,
- Enclosure of fuel elements in the reactor pressure vessel and reactor coolant system,
- Gastight containment.



Safety barriers of a nuclear power plant to avoid release of radioactive substances and ionizing radiation

Safety report

Nuclear facilities must be designed such that the protective targets in the Atomic Energy Act are observed. This not only applies to normal operation and operational malfunctions that are insignificant from the safety aspect, but also to incidents and damage events. Therefore, the safety report of a nuclear power plant must - apart from chapters dealing with the location, detailed technical plant description, radiological and climatic effects on the environment - also include information on incident effects. Within the scope of the licensing procedure the safety report must be made available for public inspection. It serves as an essential basis for experts and authorities for examination concerning granting or refusing of a licence.

Saturated steam

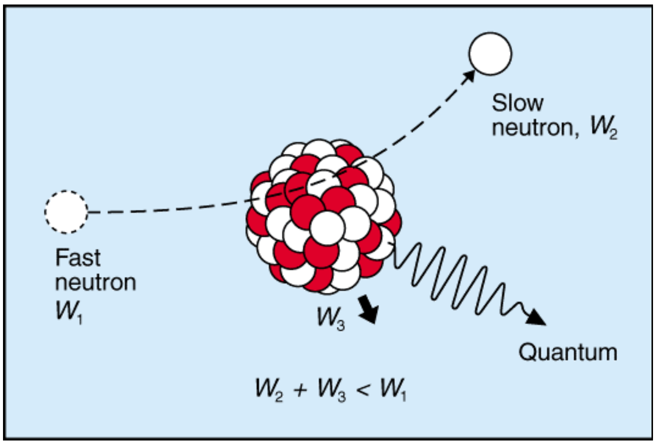
→wet steam

Scattering

Process whereby collision with another particle or particle system causes a change of direction or energy of an incident particle or quantum.

Scattering, inelastic

Scattering where the sum of kinetic energy is different before and after the collision.



Inelastic scattering of a neutron

Scintillation counter

Detection device for ionizing radiation by registering flashes of light (scintillations) generated by the radiation in certain materials, the scintillators.

Scintillator

Substance in which flashes of light are generated by impinging ionizing radiation (fluorescence). NaI(Tl)-monocrystals are particularly suitable for the detection of gamma radiation and anthracene or diphenyl oxazole dissolved in toluene is suitable for beta radiation. ZnS(Ag) is a favourable scintillator for detection of alpha radiation.

Scram

American usage for →trip. It is actually an acronym for "safety control rod axe man", the man assigned to insert the emergency rod on the first reactor (the Chicago pile) in the U.S.

Secondary coolant

Coolant to remove the heat from the reactor coolant system.

Secondary cooling system

Cooling circuit removing the heat from the reactor cooling system.

Secondary energy

Form of energy generated by conversion of primary energies, e.g. electricity from gas, nuclear energy, coal, oil, fuel oil, and gasoline from mineral oil, coke and coke oven gas from coal.

Seismic qualification

Design of all important safety-related plant sections of a nuclear facility from a technical and constructional point of view so that the reactor shuts down safely, is maintained in the shutdown condition, the residual heat is safely removed and the impermissible release of radioactive substances into the environment can be prevented. The design basis earthquake is the earthquake of maximum intensity for the location which, according to scientific knowledge, may occur in a region of up to 200 km taking all historical earthquakes which might have affected the site into account. The design basis earthquake is determined using data on the maximum acceleration and duration of the vibrations to be expected due to the local seismic conditions.

Self-absorption

Absorption of radiation in the radiation-emitting substance itself.

Self-heating

In the case of a high radionuclide concentration in a system, the production of decay heat may exceed the heat removal from the system. Self-heating is present in this case and is to be avoided e.g. for the storage of spent fuel elements and high active waste solutions by means of cooling.

Sellafield

Location of numerous nuclear facilities in Cumbria, England. At the Sellafield location, the reprocessing plant THORP is in operation since 1994, and the four gas-graphite reactors of the nuclear power plant Calder Hall have been operated from 1956 till 2003. Part of the Sellafield location is known under the name Windscale where an incident occurred in one of the two military plutonium reactors in 1957.

Semi-conductor counter

Detection device for ionized radiation. Advantage is taken of the effect of free charge carrier generation when semi-conductor material (germanium, silicon) is irradiated. Semi-conductor counters are particularly suitable for gamma radiation spectroscopy due to their high energy resolution ability.

Separating plant

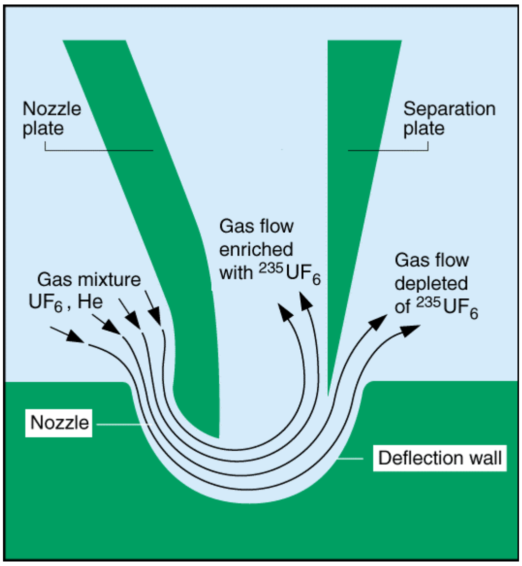
Plant for isotope separation. →diffusion separation process, →separation nozzle process, →gas centrifuge process

Separation factor

The separation factor is the quotient of the ratio of the isotope frequency of a certain isotope to the sum of isotope frequencies of other isotopes after a separation process and this ratio prior to the separation process.

Separation nozzle process

Process for isotope separation, specifically for separation of uranium isotopes. Due to the expansion of the gas jet in a bent nozzle, the centrifugal forces cause separation of the light and heavy components.



Principle of separation nozzle process

Separative work

Term from uranium isotope technology. The separative work is a measure of the input to be effected for the generation of enriched uranium.

Shield, biological

Absorber material around the reactor to reduce the quantity of ionizing radiation to values which are harmless to people. →shield, thermal

Shielding

Protection facility around radioactive sources and nuclear installations to reduce their radiation to the outside according to the requirements. →shield, biological; →shield, thermal

Shield, thermal

Shield of a reactor between reflector and biological shield; used to reduce radiation damages and irradiation heating in the pressure vessel and in the biological shield.

Shim rod

In a nuclear reactor, shim rods are used to compensate for the excess reactivity of a freshly loaded reactor and to influence the neutron flux distribution.

Shipper/receiver difference

A term from nuclear material monitoring; the difference in the quantity of nuclear material in a batch between the data of the sending →material balance zone and measurement of the receiving material balance zone.

Short-lived radionuclides

The Radiation Protection Ordinance defines radioactive substances with a half-life of up to 100 days as short-lived radionuclides.

Short-time dispersion

Term for the determination of radiation exposure by short-time emission. The environmental exposure due to short-time pollutant release for about up to one hour during which the meteorological variables of influence such as wind velocity and direction in addition to the diffusion category do not change can be included in the dispersion calculation by the short-time dispersion factor.

Shutdown reactivity

→reactivity of a reactor in a →subcrital state folllowing shutdown by usual means. In general it depends on the mode of operation of the reactor and the duration of the shutdown state and is always negative.

Shutdown rod

Shutdown rods are used to trip the reactor. For this purpose it must be possible to insert them very quickly and they must have a sufficiently high negative reactivity to safely shutdown the reactor. →control rod

Sievert

Special unit name for the organ dose and the effective dose, →dose; symbol: Sv; named after Rolf Sievert (1896 to 1966), a Swedish scientist who rendered outstanding services to the establishment and further development of radiation protection. 1 Sv = 100 Rem.

Single failure

A failure caused by a single event, including the consequential failures resulting from this failure.

Skin dose

The skin dose $H_p(0.07)$ is the dose equivalent at a depth of 0.07 mm in the body at the application point of the personal dosimeter. →dose

Skyshine

Scattered radiation of a primary gamma radiation source generated by aerial dispersion.

SNR-300

Planned fast sodium-cooled reactor in Kalkar/Rhine, with an electric gross output of 327 MW. After being almost totally completed, the reactor did not enter service for political reasons.

Soft tissue

For dosimetric purposes, soft tissue is a homogenous material with a density of 1 and a composition (according to the mass contents) of 10.1% hydrogen, 11.1% carbon, 2.6% nitrogen and 76.2% oxygen.

Solidification

As a rule, radioactive waste becomes suitable for ultimate disposal by embedding in a matrix. The stability of the solidification product is adjusted to the requirements of the type of waste, for instance, radiotoxicity, decay heat, half-life and others. Solidification criteria are:

- mechanical resistance to avoid dispersion,
- radiation protection resistance to avoid radiolysis,
- thermal conductivity to remove decay heat.

Cement mortar is used for low and medium active waste and borosilicate glass is used for high active waste as a solidification material.

Solvent extraction

Process used to selectively extract substances from an aqueous medium in an organic solvent which cannot be blended with the medium. The process of solvent extraction is applied in the →PUREX process for the separation of fission products from uranium and plutonium.

Source material

Term from the field of nuclear material monitoring; source materials are uranium which contains the naturally occurring isotope mixture, uranium where the U-235 content is below the natural content and thorium.

Spallation

Nuclear conversion during which an energy-rich bombardment particle knocks out numerous individual particles (protons, neutrons) from the target nucleus. Observed initially as an effect of cosmic radiation.

Spark chamber

Device to detect nuclear radiation. The spark chamber is made up for example of a number of metal plates arranged in parallel with a voltage of some thousand volts between each other. The spaces between the plates are filled with gas. The ionizing radiation leads to spark formation between the plates along the path of radiation through the chamber. The spark trace can be registered photographically or electronically.

Spin

Spin is a characteristic property of elementary particles.

SSK

→Commission on Radiological Protection

State collecting facilities

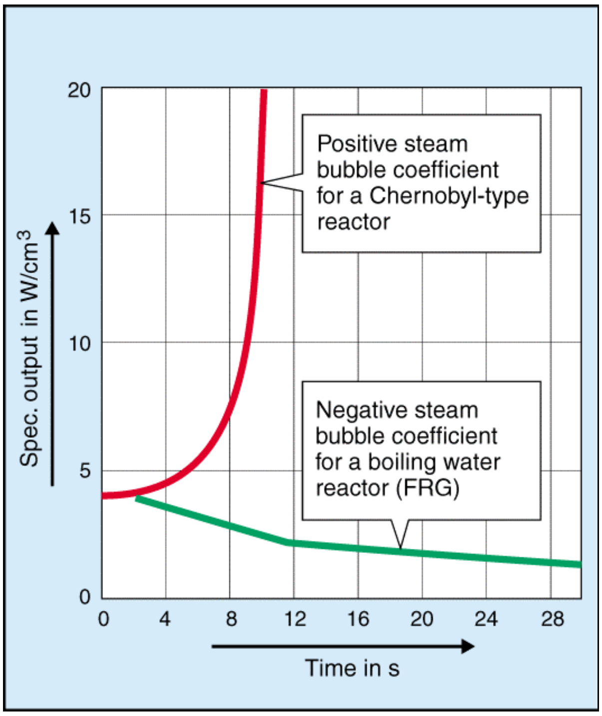
Facilities of the Federal States for the collection and interim storage of radioactive waste arising in their respective region, insofar as this does not originate from nuclear power plants.

State, excited

→excited state

Steam bubble coefficient

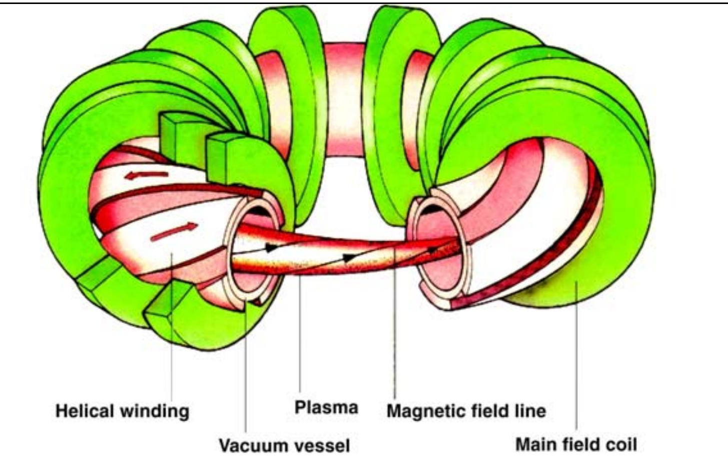
The →reactivity of a reactor - a measure for the deviation of the chain reaction rate from the stable state of equilibrium - depends upon a number of operating parameters, in a boiling water reactor, among others, on the steam bubble contents in the coolant in the core zone. In the case of an increase in the chain reaction rate and the resulting power and temperature increase, a negative steam bubble coefficient has the effect that the power is automatically limited by the growing steam bubble contents and thus declines. In the German licensing procedure it must be verified that the steam bubble coefficient is always negative. In the Russian →RBMK reactor type the steam bubble coefficient is positive; therefore, a power and temperature increase causes an increasingly faster chain reaction rate, entailing further power and temperature increases, if they are not limited by other measures. This effect was one of the physical causes for the reactor accident in Chernobyl.



Evolution of reactor power under certain circum-stances at positive and negative steam bubble coefficients

Stellarator

Experimental arrangement for controlled nuclear fusion. In a stellarator, the screw-like twisting of field lines around the torus centre is generated by external coils. In contrast to the →Tokamak, a stellarator does not need a direct-axis flow component in the plasma. The stellarator can therefore function stationarily in principle. In a stellarator, the magnetic field cage is formed by a single coil system. The abandonment of the annular plasma flow signifies, however, the abandonment of the axial symmetry existing in Tokamaks; plasma and magnetic coils have a more complicated shape. For a fusion power plant, the stellarators could provide a technically simpler solution than Tokamaks. This issue cannot be answered theoretically; it must be decided by experiments which is the aim of the WENDELSTEIN experiments of the Max Planck Institute for Plasma Physics.



Principle of the stellarator

Stochastic radiation effect

Effects of ionizing radiation, whereby the probability of their occurrence, but not their severity is a function of the dose without the existence of a threshold value. Non-stochastic effects, today called deterministic radiation effects, are those in which the severity of the effect varies with the dose and for which a threshold value exists. In the dose range relevant for radiation protection purposes, inheritable damage, cancer and leukaemia belong to stochastic radiation damages. The probability that stochastic radiation damage will occur differs widely for the irradiated individual organs or tissues. The International Commission on Radiological Protection (Publication 103, 2007) indicates a value of 5.5 % per sievert for cancer and 0.2 % per sievert for heritable effects after exposure to radiation at low dose rate. The following calculation is designed to illustrate this value: the natural radiation exposure in Germany of 2.1 mSv/year results in a total dose of 172 000 Sv for the approximately 82 million inhabitants. If this value is multiplied by the aforementioned risk factor of 5.5 % per sievert for cancer mortality, 9 500 cancer deaths annually by natural radiation result on a calculatory basis.

Storage ring

Device of high-energy physics. Particles (protons, electrons), accelerated to high energies using a particle accelerator, are stored in groups within magnetic field arrangements in an annular vacuum tube. To achieve nuclear reactions, these particle groups may be directed against particle groups orbiting in the reversed direction. Better utilization of the particle energy is therefore obtained in the collisions.

Subcritical arrangement

Arrangement of fissile material and any moderator, the →multiplication factor of which is below 1 and thus a chain reaction cannot be maintained.

Subcritical mass

Fissile material quantity insufficient in volume or geometrically arranged in such a way that no chain reaction can be maintained.

Suitable for ultimate waste disposal

Waste which has been treated with the aim of reducing the volume and increasing its resistance to leaching.

Supercritical arrangement

Arrangement of nuclear fuel where the effective →multiplication factor due to fuel quantity, geometric arrangement, moderation and reflection is greater than 1.

Supercritical reactor

Nuclear reactor where the effective multiplication factor is greater than 1. The reactor power increases continuously in this case.

SUR-100

Siemens-Unterrichts-Reaktor; a reactor with a permanent power of 100 milliwatt built for training purposes. The SUR-100 is a homogenous reactor; the core consist of a mixture of uranium enriched to 20% and polyethylene.

Synchro-cyclotron

→cyclotron, in which the frequency of the acceleration voltage decreases after a while so that it adjusts exactly to the orbits of the accelerated particles. The decrease in particle acceleration results from the mass increase with energy as described in specific relativity theory. About 700 MeV for protons are achievable.

Synchrotron

Accelerator in which particles travel on an orbit with a fixed radius. The acceleration is effected by electric fields and guidance on the orbit by magnetic fields. The orbit of the DESY synchrotron HERA in Hamburg has a length of 6.3 km. The larger the diameter , the higher the particle energies which can be obtained.

T

Tail-end

The final process section of reprocessing for the manufacture of the final products to be supplied to the fuel element manufacturers. Final products are uranyl nitrate solution and plutonium nitrate solution.

Tandem accelerator

Special design of a Van de Graaff accelerator. For instance, negative H-ions are accelerated, recharged due to interaction with matter (stripping off the electrons) and the protons further accelerated by passing once again through the same potential difference.

Target

Piece of matter on which radiation impinges, causing nuclear conversion in this matter.

TBP

→tributyl phosphate

Temperature coefficient of reactivity

Describes the reactivity changes occurring when the operating temperature of a reactor changes. The coefficient is negative when a temperature increase reduces the →reactivity. Negative temperature coefficients are desirable from the safety point of view, because they help to avoid reactor excursions.

Terrestrial radiation

Radiation emitted from the natural radioactive substances in the ground. Terrestrial radiation causes external radiation exposure of human beings. →radiation exposure, terrestrial

Thermal breeding reactor

Breeding reactor in which the fission chain reaction is maintained by thermal neutrons. Thermal breeding reactors convert non-fissionable Th-232 in fissionable U-233. →breeding reactor

Thermal column

Component part of some research reactors for generation of thermal neutrons for experiments. The column consists of a large moderator accumulation (often graphite) in addition to the core or the reflector of the reactor. Neutrons exiting the reactor enter the thermal column where they decelerated. The proportion of thermal neutrons in the overall neutron spectrum is therefore considerably increased.

Thermionic conversion

Conversion of heat in electricity by evaporation of electrons from a hot metal surface and condensation on a cooler surface. No mechanically movable parts are required.

Thermoluminescence dosimeter

Radio-thermoluminescence is the property of a crystal to emit light when heated when the crystal has previously been exposed to ionizing radiation. In wide areas, the emitted amount of light is proportional to the irradiated dose. For instance, the radio-thermoluminescence effect of calcium or lithium fluoride is used to determine the dose.

Thermonuclear reaction

Nuclear reaction in which the particles involved obtain the reaction energy necessary for the reaction from the thermal movement. →fusion

THORP

Thermal **O**xide **R**eprocessing **P**lant, Sellafield, Lake District, England. Reprocessing plant for oxidic fuel elements with a maximum annual throughput of 1 200 t uranium. Since 1964 a reprocessing plant for magnox and AGR fuel elements from British reactors has also been in operation at the Sellafield location (formerly Windscale).

Three Mile Island

Nuclear power plant near Harrisburg, Pennsylvania, USA, with two pressurized water reactors. On 28th March 1979, a serious accident with partial core melt-down occurred in unit 2. The fission products were almost completely retained in the reactor pressure vessel and in the containment. As the retention function of the containment functioned as designed, only activity releases of xenon-133 and very low portions of I-131 into the environment occurred, resulting in the calculatory maximum dose of 0.85 mSv.

Threshold detector

Detector to trace neutron radiation above a certain energy value (threshold energy). Sulphide for example is a threshold detector. Only neutrons with an energy > 2 MeV are measured via the reaction S-32 (n, p)P-32.

Threshold dose

Smallest energy or body dose causing a certain effect.

THTR-300

Thorium high-temperature reactor in Hamm-Uentrop/Lippe, high-temperature reactor with an electrical gross output of 308 MW, nuclear commissioning on 13th Sep. 1983. Final shutdown 29th Sept 1988. The plant has been in safe enclosure condition since February 1997.

Time-of-flight analyzer

Device to determine the velocity distribution of particles in a ray of particles. The different time of flight for a given distance is measured. The time-of-flight analyzer is used e.g. to determine the neutron energies.

Tissue equivalent

Term from radiation protection measuring technology; tissue equivalent denotes a substance, with absorbing and scattering properties for a given radiation that sufficiently match those of a certain biological tissue.

Tissue weighting factor

Different probabilities exist for the occurrence of stochastic radiation effects in various organs and tissues. This different sensitivity to stochastic radiation damage is considered in the ICRP Publication 60 and in the Euratom basic standards for Radiation Protection dated May 1996 by the tissue weighting factor in calculations of the effective dose. To calculate the effective dose, the individual organ dose values are multiplied by the respective tissue weighting factor and the products added.

Organ	Tissue weighting factor w_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12

Organ	Tissue weighting factor w_T
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Bone surface	0.01
Adrenals, brain, small intestine, kidney, muscle, pancreas, spleen, thymus, uterus (the weighting factor 0.05 is applied to the average dose of these organs)	0.05

Tissue weighting factors, EU Basic Safety Standards 1996

The numerical values indicated above are valid legal EU-regulations for calculating the effective dose. In 2007 ICRP published a new set of tissue weighting factors (ICRP Publ. 103: The 2007 Recommendations of the International Commission on Radiological Protection) given below. These data are adopted in the proposal of the new EU Basic Safety Standards (European Commission, Proposal for a Council Directive, COM(2011) 593 final, 2011-09-29) to be accepted by the Council of the European Union.

Tissue	Tissue weighting factor w_T	$\Sigma\ w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04

* Remainder tissues:
Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀)

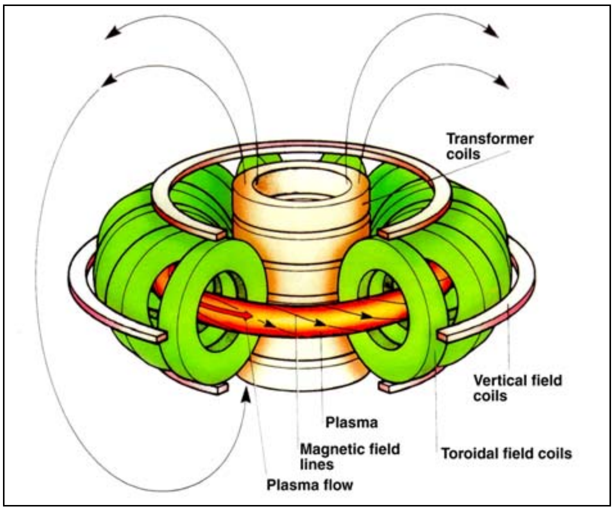
Tissue weighting factors, ICRP 2007

TLD

→thermoluminescence dosimeter

Tokamak

Experimental arrangement for controlled nuclear fusion. In a Tokamak, two superimposed magnetic fields enclose the plasma: this is the toroidal field generated by external coils on the one hand and the field of a flow in the plasma on the other hand. In the combined field, the field lines run helicoidally around the torus centre. In this way, the necessary twisting of the field lines and the structure of the magnetic areas are achieved. Apart from the toroidal field generated by the external field coils and the field generated by the flow in the plasma, the Tokamak requires a third vertical field (poloidal field), fixing the position of the flow in the plasma container. The flow in the plasma is mainly used to generate the enclosing magnetic field. In addition, it provides effective initial heating of the plasma. The flow in the plasma is normally induced by a transformer coil. Owing to the transformer, the Tokamak does not work continuously, but in pulse mode. Since, however, a power plant should not be operated in pulse mode for technical reasons, methods are examined to generate a continuous flow - for example by high-frequency waves. The fusion research plant →JET is built according to the Tokamak principle. The fusion reactor →ITER is also planned according to this principle.



Tokamak principle

Traceability limit

Fixed characteristic value based on statistical processes to evaluate the detection possibility for nuclear radiation measurements. The numerical value of the traceability limit indicates the smallest amount which can be detected with the measuring procedure concerned at a given error probability. This is the basis for the decision whether a measuring method meets certain requirements and is therefore suited for the given measuring purpose. →detection limit. Examples for traceability limits to be achieved from the guideline for the environmental monitoring of nuclear power plants:

Gamma local dose:	0.1 mSv/year,
Aerosols*:	0.4 mBq/m^3,
Precipitation*:	0.05 Bq/l,
Vegetation*:	0.5 Bq/kg,
Vegetable food*:	0.2 Bq/kg,
Vegetable food, Sr-90:	0.04 Bq/kg,
Milk, I-131:	0.01 Bq/l.

* activity of individual radionuclides, determined by gamma spectrometry, traceability limit related to Co-60

Tracer

Radionuclide added to identify substances to allow examination of mixing, distribution and transport processes via the radiation emitted by the tracer.

Transients

Any essential deviation of the operating parameters of a nuclear power plant (among others power, pressure, temperature, coolant throughput) from the setpoint values leading to an imbalance between heat generation and heat removal in the reactor.

Transmutation

Conversion of the long-lived nuclides of the elements plutonium, neptunium, americium and curium, generated during operation of nuclear reactors by neutron capture in U-238. Particularly for direct ultimate waste disposal of spent fuel elements, the partly very long half-lives of the nuclides Np-237, Pu-238, Pu-239, Pu-240, Am-241, Am-243, Cm-243 and Cm-244 emitting alpha radiation require proof of safe storage over very long periods. By nuclear conversions, either due to direct fission as for Pu-239 or conversion in easily fissionable nuclides by neutron capture relatively short-lived or stable fission products are finally produced. For this purpose, it is necessary to reprocess the spent nuclear fuel, to separate these transuranium elements from the fission products and to convert them in suitable nuclear reactors using neutrons. In addition to the reactors as neutron source for the conversion, subcritical arrangements driven by accelerators are discussed as a possibility of „burning“ Pu and higher actinides. Since a high number of neutrons can be provided by a strong proton beam from an accelerator and the resulting spallations in a suitable target material, a good prerequisite exists for such transmutation machines. As no self-perpetuating chain reaction takes place in such facilities, advantages with regard to safety behaviour are expected.

Transport of radioactive substances

The conveyance of radioactive substances by public transport requires a permit, in principle. Depending on the type and quantity of the transported radioactive substances, certain packaging regulations must be observed. The so-called type B packaging required particularly for the transport of spent fuel elements must withstand the following tests in compliance with internationally agreed rules:

- Free fall from 9 m height onto a concrete foundation reinforced with a steel plate,
- Free fall from 1 m height onto a steel spike with 15 cm diameter and a length of at least 20 cm,
- Fire test at 800 °C for 30 minutes following the fall tests,
- Submersion in water for 15 hours at a depth of more than 15 m or for 1 hour at 200 m for packages with very high activities.

In the USA, England and Germany this type of container was subjected to even higher loads in special test series without the containers losing their seal:

- Collision between the means of fuel element transport and a locomotive (relative speed 130 km/h).
- Fall from 600 m height on to hard desert ground (results in a maximum impact speed of 400 km/h),
- Impact of a missile of several tonnes at a speed of 300 m/s = 1080 km/h.

Transuranium element

Chemical element in the classification of elements, the atomic number of which is greater than 92, that of uranium. Except for the plutonium isotopes Pu-244 (half-life about 80 million years) and Pu-239 (continuous reformation in uranium by neutron capture in U-238 by neutrons from the spontaneous fission of U-238) detected in very small quantities, all transuranium elements must be produced artificially.

Element name	Symbol	Atomic no.
Neptunium	Np	93
Plutonium	Pu	94
Americium	Am	95
Curium	Cm	96
Berkelium	Bk	97
Californium	Cf	98
Einsteinium	Es	99
Fermium	Fm	100
Mendelevium	Md	101
Nobelium	No	102
Lawrencium	Lw	103
Rutherfordium	Rf	104
Dubnium	Db	105
Seaborgium	Sb	106
Bohrium	Bh	107
Hassium	Hs	108
Meitnerium	Mt	109
Darmstadtium	Ds	110
Roentgenium	Rg	111
Copernicium	Cn	112
Still without name		113
Flerovium	Fl	114
Still without name		115
Livermorium	Lv	116
Still without name		117
Still without name		118

Transuranium elements

Tributyl phosphate

Used in reprocessing for the →PUREX process as an organic extraction agent for U and Pu extraction from nuclear fuel solution. In the PUREX process, TBP is diluted to 15 to 40% with kerosene.

TRIGA

Abbreviation for: Training, Research and Isotope Production Reactor of General Atomic. A research reactor of the TRIGA type is operated at the university of Mayence.

Trip

Fast shutdown of a nuclear reactor, generally by fast insertion of the shutdown rods. Emergencies or deviations from normal reactor operation lead to the automatic control system initiating the reactor trip.

Tritium

Radioactive isotope of hydrogen with two neutrons and a proton in the nucleus. Tritium is used e.g. in the manufacture of luminous paint, as an indicator in tracer tests and as a fuel in controlled fusion experiments. Tritium is a beta emitter ($E_{\beta max}$: 18 keV) with a half-life of 12.323 years.

Triton

Atomic nucleus of →tritium. The nucleus consist of one proton and two neutrons.

TUSA

Turbine trip.

U

Ultimate waste disposal, Germany

Maintenance-free, chronologically unlimited and safe elimination of radioactive waste without intended recuperation. In Germany the storage of radioactive waste in deep geological formations is considered the best solution. The following repositories are under examination or being operated in Germany:

- Procedures and techniques for ultimate radioactive waste disposal were developed and tested in the disused former salt mine →Asse near Wolfenbüttel and low and medium active waste was stored there until 1978. The long term stability of the storage area is highly doubtful due to saline inflow. According to the current state of decision makers the long-term safety can only be ensured for the Asse site after all the waste has been retrieved.
- Suitability examinations and licensing procedures for the former ore mine Konrad have been under way since 1975. Here, the ultimate disposal of waste with a negligible thermal effect on the surrounding rock is planned. On June 5, 2002, the licence for the emplacement of a waste package volume of 300.000 m^3 of radioactive waste with negligible heat generation was issued. The Federal Administrative Court on March 26, 2007 confirmed the lawfulness of the licence. Completion of the repository is expected in 2019.
- The Gorleben salt dome has been investigated for its suitability as a repository for all types of solid radioactive waste, i.e. also heat-generating waste, since 1979. A final suitability statement for the Gorleben salt dome will be possible only after the underground reconnaissance. The evaluation of all reconnaissance results to date confirms its suitability. In the opinion of the Federal Government, there are doubts concerning the suitability of the salt dome. Therefore, the investigation was suspended.
- The storage of radioactive waste in the ERAM repository near Morsleben in Saxony-Anhalt was terminated in 1999. At present, 36,754 cubic meters of low and medium active waste is stored in the Morsleben repository. The Federal Office for Radiation Protection is initiating a procedure for official approval of a plan to shut down the repository.

Ultimate waste disposal, direct

Direct ultimate waste disposal means that the entire fuel element including the valuable substances uranium and plutonium is disposed of as radionuclide waste following interim storage to allow decay of the short-lived radionuclides and a related reduction in the heat generation. In a conditioning plant, the fuel elements are dismantled, packed in special drums suitable for ultimate disposal before being stored as radioactive waste in a repository. In Germany, this method of disposal has been developed supplementing disposal with reprocessing. The establishment of a pilot conditioning plant in Gorleben is intended to verify the technical feasibility of conditioning spent fuel elements. In parallel, a demonstration programme proved the safe handling and the safe inclusion of conditioned fuel elements in a repository. The amendment of the Atomic Energy Act 1994 provided the legal prerequisites for direct ultimate waste disposal in Germany. According to the agreement between the Federal Government and the nuclear power plant operators, the disposal of spent fuel elements from nuclear power plants will be limited to direct ultimate waste disposal from 1st July 2005 onwards.

UNSCEAR

United Nations Scientific Committee on the Effects of Atomic Radiation; scientific committee of the General Assembly of the United Nations on the effects of ionizing radiation. UNSCEAR regularly prepares reports for the UN General Assembly on radiation exposure and the effects of ionizing radiation. The latest publication is the UNSCEAR 2010 Report: "Summary of low-dose radiation effects on health". The penultimate publication was the UNSCEAR 2008 Report: "Sources and effects of ionizing radiation".

Uranium

Natural radioactive element with the atomic number 92. The naturally occurring isotopes are fissionable uranium-235 (0.7205% of natural uranium), uranium-238 which cannot be fissioned with thermal neutrons (99.2739% of natural uranium) and the uranium-234, a decay product of radioactive decay of uranium-238 (0.0056%).

Uranium, depleted

Uranium with a lower percentage of U-235 than the 0.7205% occurring in natural uranium. It is produced during →uranium isotope separation.

Uranium, enriched

Uranium in which the percentage of fissionable isotope U-235 is increased beyond the content of 0.7205% of natural uranium. Various enrichment processes are possible: →diffusion separation process, →gas centrifuge process, →nozzle separation process.

Uranium hexafluoride (UF_6)

UF_6 is the process medium for all separation processes for uranium enrichment. It is essential that fluoride be a pure element and therefore solely the mass differences of U-235 and U-238 determine the separation process.

Uranium mining, global

Country	Uranium mining in tonnes
Australia	5,983
Brazil	265
Canada	9,145
China	1,500
Czech Republic	229
Germany	52
France	6
India	400
Kazakhstan	19,451
Malawi	846
Namibia	3,258
Niger	4,351
Pakistan	45
Romania	77
Russia	2,993
Republic of South Africa	582
Ukraine	890
USA	1,537
Uzbekistan	3,000
Global total	54,610

Uranium production 2011 (in t uranium)

Uranium resources

The global uranium resources with mining costs up to US $ 130 per kilogram amount to about 5.4 million tonnes and 6.3 million tonnes with mining costs up to US $ 260 per kilogram. With a total annual uranium demand of 68,000 tonnes all world-wide operated nuclear power plants can be supplied for up to 200 years.

Uranium separative work

→separative work

Uranyl nitrate

Final product of reprocessing, $UO_2\,(NO_3)_2$, acid uranium solution; preliminary product of UF6 which is obtained by →conversion and after enrichment and transfer into UO_2 is used as nuclear fuel in fuel elements.

Useful energy

The portion of final energy which is actually available after final conversion to the consumer for the respective use. In final conversion, electricity becomes for instance light, mechanical energy or heat.

UTA

Uranium separative work; →separative work.

Utilization ratio

In contrast to efficiency, which compares the energy input with the useful energy over a short period of time, both are related for a long period of time for the utilization ratio. Thus, an oil-fired heating system may have an efficiency of 90% reached at nominal load. If only partly utilized in the transitional period (e.g. summer) higher standstill losses occur so that a utilization ratio of only 65% annually results.

V

VAK

Versuchsatomkraftwerk (experimental nuclear power plant) Kahl/Main, boiling water reactor with an electric gross output of 16 MW. Nuclear commissioning took place on 13th Nov. 1960. VAK was the first nuclear power plant in the Federal Republic of Germany. End of November 1985 it was finally put out of operation. On 24th Sept 2010 decommissioning was completed. The cumulated power generation amounted to 2.1 TWh.e cumulated power generation amounted to 2.1 TWh.

Van de Graaff generator

Machine to generate very high direct voltages used to accelerate charged particles to high energies (up to 12 MeV). By means of a non-conductive endless strip, electrical charges are transported to an insulated hollow sphere which is thereby charged to very high voltages.

Vitrification

The highly active fission product solutions arising in reprocessing must be transferred to a product suitable for ultimate disposal. Vitrification has proven to be a suitable method for this purpose. In the French AVM process, the liquid high active waste solution is heated to high temperatures which causes the liquid to evaporate and the resulting granulate is molten at 1 100 °C to glass adding glass frit. This process is used in the French large-scale reprocessing plant La Hague. In the process developed by the Karlsruhe Research Centre, liquid high active waste solution is added directly to the molten glass mass at 1 150 °C. The liquid evaporates and the radioactive solids are homogenously embedded in the molten glass mass. In both processes the molten glass mass is filled into 1.3 m high 150 l steel containers holding about 400 kg glass product. The heat production due to the radioactive decay of the ingredients of such a container amounts to 1.5 to 2 kW.

Vitrification plant Karlsruhe

Plant on the premises of the reprocessing plant Karlsruhe for the vitrification of the around 60 m^3 liquid high active waste solution stored there. This waste comes from the operation of the reprocessing plant Karlsruhe where a total of 208 t spent nuclear fuel was reprocessed between 1971 and 1990. The 60 m^3 fission product solution contain about 8 t solids, including 504 kg uranium and 16.5 kg plutonium. The total activity of this liquid high active waste amounts presently to about 10^{18} becquerel. The glass melting furnace of the vitrification plant is electrically heated and keeps the molten mass bath of a special boron silicate glass at a temperature of approx. 1150 °C. The liquid waste is added to this bath where the liquid component evaporates and the radioactive solids are embedded in the molten glass mass. The latter containing radioactivity is filled into 1.3 m high 150 l steel canisters. Following cooling, the canisters are welded gas-tight. This solidification enables a volume reduction from 60 m^3 to barely 20 m^3. On June 22, 2010 the vitrification of the 60 m^3 fission product solution was completed, producing a total of 122 canisters.

Void effect

The formation of steam or the ingress of gas bubbles in the moderator and/or the coolant influence the criticality of the reactor. The void effect can be decisively influenced by the design of the reactor core. Since e.g. in the case of a thermal reactor there is an optimum ratio of moderator to fuel volume, there is a void effect with positive coefficient in an excessively moderated reactor. An increase in the steam bubble portion increases the neutron multiplication factor and thus the reactor power. In a reactor undermoderated due to the core design the conditions are the other way around; here the increase of the steam bubble portion reduces the neutron multiplication factor and thus the reactor power. Therefore, an inherently safe reactor regarding steam bubbles and gas ingress must always be slightly undermoderated; it has a negative void coefficient. →steam bubble coefficient

W

WAK

→reprocessing plant Karlsruhe

Waste heat

The efficiency of a thermal power plant is the ratio of electricity generated to the heat generated. Due to physical laws, the efficiency depends on the temperature of the process medium and amounts to about 34% for a light water reactor and 40% for a modern coal-fired power plant. The majority of the generated heat in these thermal power plants is discharged to the environment via the condenser cooling water.

Waste management

All facilities and process steps in nuclear engineering required for the further treatment of the spent fuel from a reactor: interim storage, reprocessing with return of usable fission material or conditioning of spent fuel elements and direct ultimate storage, treatment and ultimate radioactive waste disposal. The opposite is the supply of the reactor with nuclear fuel: search, mining, treatment, enrichment of uranium, manufacture of fuel elements. →nuclear fuel cycle

Waste processing

Solid, liquid or gaseous radioactive waste is produced in the overall →nuclear fuel cycle, in particular in the nuclear power plant and during →processing. This has to be processed for →ultimate waste disposal. A distinction is made between low, medium and high active waste. Another distinctive criterion is the heat generated by radioactive decay and the resulting classification into waste which generates heat and waste that does not generate heat. Low and medium active waste is compacted in chemical or physical processes and the concentrates subsequently solidified in cement. Vitrification is a suitable method to convert high active heat-generating waste into a product for ultimate waste disposal.

Waste water path

Assumption models to calculate the →radiation exposure through radioactive waste disposal in the waste water of a nuclear plant. The radiation generated during the decay of these radionuclides may in principle lead to a radiation exposure for human beings via the following paths:

External irradiation through spending time on sediment,
Internal irradiation through ingestion of radioactive substances with food via
drinking water,
water – fish,
watering tank – cow – milk,
watering tank – animal – meat,
rainfall – forage plant – cow – milk,
rainfall – forage plant – animal – meat,
rainfall – plant,
mother's milk

Models and calculation assumptions for radiation exposure via the waste water path are included in the administrative instruction "Determination of radiation exposure through radioactive waste disposal from nuclear plants or facilities".

Waste, radioactive

Radioactive substances which should be eliminated or must be properly eliminated in a controlled manner for radiation protection reasons.

Waste, radioactive, classification

Radioactive waste used to be classified in Germany according to its dose rate as low active waste (LAW), medium active waste (MAW) and high active waste (HAW:) This differentiation is still valid in many countries. This classification, however, makes no sense for safety-analytical considerations regarding ultimate waste disposal since the dose rate is not decisive in this context. It is the radioactive inventory and the heat generated during the radioactive decay process that are important. These parameters are required for the emplacement operation, for the technical design to control incidents and for the post-operation phase of the repository. For geological reasons no considerable temperature increases should occur in the planned "Konrad" repository. Therefore, the temperature increase in the host rock of the emplacement section has been limited to 3 Kelvin. The admissible heat output of a waste package results from this specification.

Waste, radioactive, from nuclear power plants

Raw radioactive waste is produced in nuclear power plants through cleaning of the cooling circuit, air and water from control areas and cleaning of the system. Spheroidal resin and filter cartridges are used to clean the cooling circuit, e.g. in pressurized water reactors. Evaporation drying systems, centrifuges and ion-exchange filters are used to clean the waste water. The air is cleaned with filters. Combustible and compactable waste in particular is produced during cleaning of the system. The raw waste is either treated directly in the nuclear power plant or in an external waste conditioning plant. Procedures such as drying, compacting or burning result in a considerable volume reduction. Procedures increasing the volume such as cementing are rarely used today. The annual volume of radioactive waste produced through the operation of a 1300 MWe nuclear power plant with a pressurized water reactor amounts to:

- Ion-exchanger resins 2 m^3,
- Evaporator condensate 25 m^3,
- Metal parts, insulating material 60 m^3,
- Paper, textiles, plastics 190 m^3.

The annual volume of radioactive waste produced through the operation of a 1300 MWe nuclear power plant with a boiling water reactor amounts to:

- Ion-exchanger resins 8 m^3,
- Evaporator condensate 35 m^3,
- Filter auxiliaries, sludges 90 m^3,
- Paper, textiles, plastics 300 m^3.

Waste, radioactive, volume

The inventory of radioactive waste in Germany is regularly recorded by the Federal Office for Radiation Protection. The conditioned waste volume with negligible heat generation amounted to 130,900 m^3 at the end of 2011. The volume of heat producing waste amounted to about 2,000 m^3. According to a current prediction the waste volume by the year 2060 is estimated to approx. 300,000 m^3 for waste with negligible heat generation and of 28,100 m^3 for heat producing waste.

Waste, radioactive, volume reduction

Typical raw wastes from a 1 300 MWe nuclear power plant are combustible and compactable waste. The raw waste is pre-sorted into combustible and non-combustible substances. The non-combustible but compactable waste is compacted. The volume reduction factor is about 2 to 5. The combustible waste is burnt. The ash volumes amount to as little as 1/50 of the raw waste volumes. The ash volumes may be reduced further by the factor of two using a high-pressure press.

Weighting factor

→tissue weighting factor

Wet cooling tower

Cooling tower for the closed-circuit cooling of water where the water to be cooled comes into direct contact with the cooling air dissipating heat by evaporation and air heating. The air draught required for cooling can be induced by fans or by the natural effect of the stack of the cooling tower building (natural draught cooling tower).

Wet steam

Mixture of liquid and steam of the same substance in which both are at saturation temperature. If additional heat is added to the wet steam at constant pressure, the temperature remains constant until all liquid is evaporated (saturated steam); it is only at this point that the temperature increases above the saturation temperature (superheated steam).

Wet storage

Storage of irradiated fuel elements in a water basin for cooling and removal of the residual heat generated by the radioactive decay in the fuel elements. →dry storage

Whole-body dose

Average value of the dose equivalent over the head, trunk, upper arms and upper thighs as a result of irradiation of the whole body and considered as uniform. Today this term is replaced by the more comprehensive term of the effective dose. →dose

Wigner effect

Change in grid structure of graphite caused by irradiation - mainly by fast neutrons.

Wigner energy

Energy stored in the irradiated graphite of a graphite reactor. The graphite atoms located at the interstitials cause this energy storage (→Wigner effect). At graphite temperatures of more than 250 °C these voids recombine releasing energy, the Wigner energy.

Wipe test

In addition to direct measurement, the wipe test is used to determine radioactive contamination on the surface of a solid body. In this easily performed test, part of the contamination adhering to the surface is wiped off e.g. with a paper fleece and can be measured.

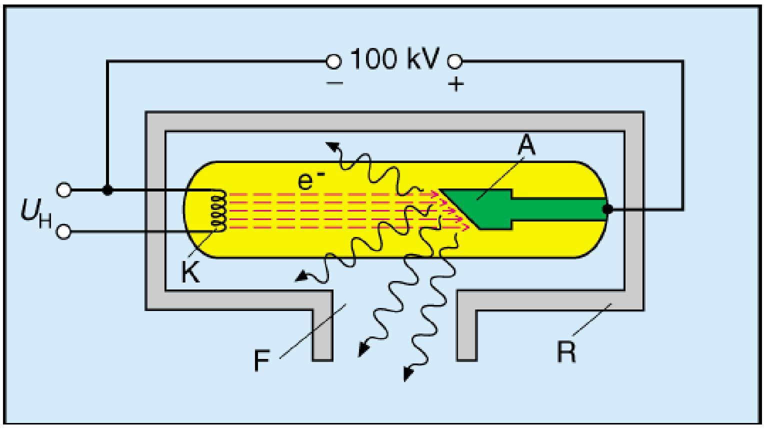
X

Xenon poisoning

Reduction of the →reactivity of a reactor by very high neutron capture in the fission product Xe-135. The increase in Xe-135 concentration after the shutdown of a reactor - Xe-135 is generated by the decay of the precursor nuclide I-135 with a half-life of 6.6 hours - may have the effect that the reactor cannot be restarted until the decay of the Xe-135 concentration - the maximum of Xe-135 concentration is reached after about 12 hours.

X-radiation

Penetrating electromagnetic radiation. X-radiation is generated by slowing-down electrons or heavy charged particles. In an x-ray tube, electrons are accelerated by means of high direct voltage to bombard a metal electrode. The bremsstrahlung generated is called x-radiation.



Simplified sectional drawing of an x-ray tube (U_H: heater voltage, K: cathode, A: anode, e: electrons exiting the cathode and accelerated to the anode, R: x-ray shielding, F: beam hole)

X-ray treatment

Irradiation of the living human or animal body or an object with x-rays to influence its constitution, condition or functions.

Y

Yellow cake

Yellowcake is obtained through the milling of uranium ore. It contains about 80% uranium oxide and is usually represented by the formula U_3O_8. The yellow cake produced by most modern mills is actually brown or black, not yellow; the name comes from the colour and texture of the concentrates produced by early mining operations.

Z

Zero effect

Number of pulses per unit of time which occur in a radiation detector for other causes than the radiation to be measured. The zero effect essentially consists of cosmic radiation and the radiation of natural radionuclides on earth.

Zero power reactor

Experimental reactor operated at such a low power that a coolant is not required.

Zircaloy

Zirconium alloy based on zircon and tin used as material for the fuel rod cladding.

Annex

Annex

Conversion of area units

	m^2	a	ha	km^2	cm^2	in^2	ft^2	yd^2	sq mile	acre
1 m^2	1	10^{-2}	10^{-4}	10^{-6}	10^4	1550	10.7639	1.198		
1 a (are)	10^2	1	10^{-2}	10^{-4}	10^6		1076.39			
1 ha (hectare)	10^4	10^2	1	10^{-2}	10^8					2.47105
1 km^2	10^6	10^4	10^2	1	10^{10}				0.3861	247.105
1 cm^2	10^{-4}	10^{-6}	10^{-8}	10^{-10}	1	0.155				
1 square inch					6.4516	1				
1 square foot	0.092903				929.03	144	1	0.111		
1 square yard	0.836127				8361.27	1296	9	1		
1 square mile			258.999	2.5899				3097600	1	640
1 acre	4046.86	40.4686	0.404686				43560	4840	0.00156	1

Conversion of volume units

	m^3	cm^3	in^3	ft^3	yd^3	US fl oz	UK fl oz	US gal	UK gal	UK pint
1 m^3	1	10^6	61024	35	1.3	33814	35195	264.2	219.9	1759.8
1 cm^3	10^{-6}	1	0.061024			0.033814	0.035195			
1 cubic inch		16.3872	1			0.5541	0.5768			0.0288
1 cubic foot	0.0283168	28316.8	1728	1	0.03704	957.5	996.6	7.4805	6.2288	49.831
1 cubic yard	0.76456		46656	27	1			201.97	168.18	1345.43
1 US fluid ounce		29.574	1.805			1	1.041			
1 UK fluid ounce		28.413	1.7339			0.96075	1			0.05
1 US gallon		3785.4	231	0.1337		128	133.23	1	0.8327	6.662
1 UK gallon		4546.09	277.42	0.1605		153.72	160	1.201	1	8
1 UK pint		568.261	34.68	0.02		19.215	20	0.1501	0.125	1

Annex

Conversion of weight units

	kg	g	t	oz	lb	sh cwt	cwt	sh tn	ton
1 kg	1	1000	0.001	35.274	2.20462				
1 g	0.001	1							
1 t	1000		1	35274	2204.62	22.0462	19.685	1.10231	0.98421
1 oz (ounce avoirdupois)		28.35		1	0.0625				
1 lb (pound avoirdupois)	0.45359	453.5924		16	1	0.01	0.0089	0.0005	
1 sh cwt (short hundredweight, US unit)	45.3592				100	1	0.8929	0.05	0.0446
1 cwt (hundredweight, Brit. unit)	50.8023				112	1.12	1	0.056	0.05
1 sh tn (short ton, US unit)	907.185				2000	20	17.857	1	0.8929
1 ton (Brit. unit)	1016.05		1.01605		2240	22.4	20	1.12	1

1 ounce (avoirdupois) = 16 drams = 437.5 troy grains; 1 troy ounce = 480 troy grains = 31.103 g
1 stone (avoirdupois) = 14 lb

Conversion of pressure units

	Pa	bar	kp/m²	at	atm	torr	lbf/in²
1 Pa	1	10^{-5}	$1.019716 \cdot 10^{-1}$	$1.019716 \cdot 10^{-5}$	$0.986923 \cdot 10^{-5}$	$0.750062 \cdot 10^{-2}$	$145.038 \cdot 10^{-6}$
1 bar	10^{5}	1	$10.19716 \cdot 10^{3}$	1.019716	0.986923	750.062	14.5038
1 kp/m² = 1 mm WS	9.80665	$0.980665 \cdot 10^{-4}$	1	10^{-4}	$0.967841 \cdot 10^{-4}$	$0.735559 \cdot 10^{-1}$	$1.42244 \cdot 10^{-3}$
1 at	$0.980665 \cdot 10^{5}$	0.980665	10^{4}	1	0.967841	735.559	14.2233
1 atm	101325	1.01325	$1.033227 \cdot 10^{4}$	1.033227	1	760	14.69595
1 torr	133.3224	$1.333224 \cdot 10^{-3}$	13.59510	$1.359510 \cdot 10^{-3}$	$1.315789 \cdot 10^{-3}$	1	$193368 \cdot 10^{-3}$
1 lbf/in² = 1 psi (pound-force-per sq. inch)	$6.89476 \cdot 10^{3}$	$68.9476 \cdot 10^{-3}$	703.070	$70.3070 \cdot 10^{-3}$	$68.0460 \cdot 10^{-3}$	51.7128	1

Conversion of power units

	kW	PS	hp	kpm/s	kcal/s	Btu/s	ft-lbf/s
1 kW	1	1.35962	1.34102	101.9716	0.238846	0.94781	737.562
1 PS (Pferdestärke)	0.735499	1	0.986320	75	0.1757	0.69712	542.476
1 hp (horsepower)	0.745700	1.01387	1	76.042	0.17811	0.70679	550
1 kpm/s (kilopond metre per second)	$9.807 \cdot 10^{-3}$	0.0133333	0.0131509	1	$2.342 \cdot 10^{-3}$	$9.295 \cdot 10^{-3}$	7.23301
1 kcal/s (kilocalorie per second)	4.1868	5.692	5.614	426.939	1	3.96832	3088.05
1 Btu/s (British thermal unit/sec)	1.05505	1.4345	1.4149	107.586	0.251993	1	778.17
1 ft-lbf/s (foot-pound-force/sec)	$1.356 \cdot 10^{-3}$	$1.843 \cdot 10^{-3}$	$1.818 \cdot 10^{-3}$	0.138255	$3.238 \cdot 10^{-4}$	$1.285 \cdot 10^{-3}$	1

Conversion of energy units

	J	kWh	PSh	hph	kpm	kcal	Btu	MeV
1 J	1	$2.778 \cdot 10^{-7}$	$3.777 \cdot 10^{-7}$	$3.725 \cdot 10^{-7}$	0.10019716	$2.388 \cdot 10^{-4}$	$9.478 \cdot 10^{-4}$	$6.242 \cdot 10^{12}$
1 kWh (kilowatt hour)	$3.6 \cdot 10^{6}$	1	1.35962	1.34102	$3.671 \cdot 10^{5}$	859.845	3412.14	$2.247 \cdot 10^{19}$
1 PSh (PS hour)	$2.648 \cdot 10^{6}$	0.735499	1	0.986320	$2.7 \cdot 10^{5}$	623.41	2509.62	$1.653 \cdot 10^{19}$
1 hph (horse-power hour)	$2.685 \cdot 10^{6}$	0.745700	1.013870	1	$273.7 \cdot 10^{3}$	641.186	2544.43	$1.676 \cdot 10^{19}$
1 kpm (kilopond meter)	9.80665	$2.724 \cdot 10^{-6}$	$3.70 \cdot 10^{-6}$	$3.653 \cdot 10^{-6}$	1	$2.342 \cdot 10^{-3}$	$9.295 \cdot 10^{-3}$	$6.122 \cdot 10^{13}$
1 kcal (kilocalorie)	4186.8	$1.163 \cdot 10^{-3}$	$1.581 \cdot 10^{-3}$	$1.560 \cdot 10^{-3}$	426.935	1	3.96832	$2.614 \cdot 10^{16}$
1 Btu (British thermal unit)	1055.06	$2.931 \cdot 10^{-4}$	$3.985 \cdot 10^{-4}$	$3.930 \cdot 10^{-4}$	107.586	0.251996	1	$6.586 \cdot 10^{15}$
1 MeV (megaelectron volt)	$1.602 \cdot 10^{-13}$	$4.45 \cdot 10^{-20}$	$6.050 \cdot 10^{-20}$	$5.968 \cdot 10^{-20}$	$1.63 \cdot 10^{-14}$	$3.82 \cdot 10^{-17}$	$1.519 \cdot 10^{-15}$	1

Annex

Conversion of force units

	N	dyn	kp	lbf
1 N (newton)	1	10^5	0.1019716	0.224809
1 dyn	10^{-5}	1	$1.019716 \cdot 10^{-6}$	$2.24809 \cdot 10^{-6}$
1 kp (kilopond)	9.80665	$9.80665 \cdot 10^5$	1	2.20462
1 lbf (pound-force)	4.44822	$4.44822 \cdot 10^5$	0.453592	1

Activity and dose units

Physical variable	SI unit	old unit	Relationship
Activity	becquerel (Bq) 1 Bq = 1/s	curie (Ci)	$1\ Ci = 3.7 \cdot 10^{10}\ Bq$ $1\ Bq \approx 2.7 \cdot 10^{-11}\ Ci$
Absorbed dose	gray (Gy) 1 Gy = 1 J/kg	rad (rd)	1 rd = 0.01 Gy 1 Gy = 100 rd
Dose equivalent	sievert (Sv) 1 Sv = 1 J/kg	rem (rem)	1 rem = 0.01 Sv 1 Sv = 100 rem
Ion dose	coulomb divided by kilogram (C/kg)	roentgen (R)	$1\ R = 2.58 \cdot 10^{-4}\ C/kg$ $1\ C/kg \approx 3876\ R$

Prefixes of decimal multiples and submultiples of SI units

Prefix	Symbol	Factor
Yotta	Y	10^{24}
Zetta	Z	10^{21}
Exa	E	10^{18}
Peta	P	10^{15}
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Hecto	h	10^{2}
Deca	da	10^{1}
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	µ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Femto	f	10^{-15}
Atto	a	10^{-18}
Zepto	z	10^{-21}
Yocto	y	10^{-24}

ANNEX

Physical Constants

Quantity	Symbol	Value	Unit
speed of light in vacuum	c, c_0	299 792 458	$m\ s^{-1}$
magnetic constant	μ_0	$4\pi \times 10^{-7}$	$N\ A^{-2}$
		$= 12.566\ 370\ 614... \times 10^{-7}$	$N\ A^{-2}$
electric constant	ε_0	$8.854\ 187\ 817... \times 10^{-12}$	$F\ m^{-1}$
Newtonian constant of gravitation	G	$6.673\ 84 \times 10^{-11}$	$m^3\ kg^{-1}\ s^{-2}$
elementary charge	e	$1.602\ 176\ 565 \times 10^{-19}$	C
(unified) atomic mass	u	$1.660\ 538\ 921 \times 10^{-27}$	kg
Planck constant	h	$6.626\ 069\ 57 \times 10^{-34}$	J s
$h/2\pi$	$\hbar$	$1.054\ 571\ 726 \times 10^{-34}$	J s
Avogadro constant	N_A, L	$6.022\ 141\ 29 \times 10^{23}$	mol^{-1}
Faraday constant	F	96 485.3365	$C\ mol^{-1}$
Rydberg constant	R_∞	10 973 731.568 539	m^{-1}
fine-structure constant	α	$7.297\ 352\ 5698 \times 10^{-3}$	
inverse fine-structure constant	α^{-1}	137.035 999 074	
molar gas constant	R	8.314 4621	$J\ mol^{-1}\ K^{-1}$
molar volume of ideal gas	V_m	$22.710\ 953 \times 10^{-3}$	$m^3\ mol^{-1}$
Boltzmann constant	k	$1.380\ 6488 \times 10^{-23}$	$J\ K^{-1}$
Stefan-Boltzmann constant	σ	$5.670\ 373 \times 10^{-8}$	$W\ m^{-2}\ K^{-4}$
first radiation constant	c_1	$3.741\ 771\ 53 \times 10^{-16}$	$W\ m^{-2}$
second radiation constant	c_2	$1.438\ 7770 \times 10^{-2}$	m K
von Klitzing constant	R_K	25 812.807 4434	Ω
Bohr magneton	μ_B	$927.400\ 968 \times 10^{-26}$	$J\ T^{-1}$
nuclear magneton	μ_N	$5.050\ 783\ 53 \times 10^{-27}$	$J\ T^{-1}$
electron			
electron mass	m_e	$9.109\ 382\ 91 \times 10^{-31}$	kg
		$5.485\ 799\ 0946 \times 10^{-4}$	u
		0.510 998 928	MeV
charge to mass quotient	$-e/m_e$	$-1.758\ 820\ 088 \times 10^{11}$	$C\ kg^{-1}$
Compton wavelength	λ_C	$2.426\ 310\ 2389 \times 10^{-12}$	m
classical electron radius	r_e	$2.817\ 940\ 3267 \times 10^{-15}$	m
electron magnetic moment	μ_e	$-928.476\ 430 \times 10^{-26}$	$J\ T^{-1}$
proton			
proton mass	m_p	$1.672\ 621\ 777 \times 10^{-27}$	kg
		1.007 276 466 812	u
		938.272 046	MeV
proton-electron mass ratio	m_p/m_e	1836.152 672 45	
Compton wavelength	$\lambda_{C,p}$	$1.321\ 409\ 856\ 23 \times 10^{-15}$	m
magnetic moment	μ_p	$1.410\ 606\ 743 \times 10^{-26}$	$J\ T^{-1}$
neutron			
neutron mass	m_n	$1.674\ 927\ 351 \times 10^{-27}$	kg
		1.008 664 916 00	u
		939.565 379	MeV
Compton wavelength	$\lambda_{C,n}$	$1.319\ 590\ 9068 \times 10^{-15}$	m
magnetic moment	μ_n	$-0.966\ 236\ 47 \times 10^{-26}$	$J\ T^{-1}$

CODATA Recommended Values of the Fundamental Physical Constants, 2010