Management in Nuclear

Study Text

Master's Degree Programme: Management in Nuclear

Vydavateľstvo Ekonóm

Bratislava 2026

Management in Nuclear: Study Text

Category: Study Text

Study Programme: Management in Nuclear (Master's level)

Institution: STUBAxEUBA Consortium — Slovak University of Technology in Bratislava & Bratislava University of Economics and Business

Authors:

Team EUBA: doc. RNDr. Zuzana Hajduová, PhD. MSc., doc. Ing. Nora Grisáková PhD., Ing. Denisa Gajdová, PhD., prof. Ing. Nadežda Jankelová, PhD. MPH, Ing. Simona Kosztanko PhD., prof. Ing. Helena Majdúchová, CSc., Ing. Katarína Procházková, PhD.Ing. Slavka Šagátová, PhD.

Team STU: Mgr. Otto Glavo, doc. Ing. Ján Haščík, PhD., doc. Ing. Róbert Hinca, PhD., Ing. Jakub Lüley, PhD., prof. Ing. Vladimír Nečas, PhD., prof. Ing. Vladimír Slugeň, DrSc., doc. Ing. Andrea Šagátová, PhD., doc. Ing. Branislav Vrban, PhD.

Reviewers:

Ing. Lucia Bursíková, PhD.
Ing. Andriana Baziuk

Edited by:

EUBA: doc. RNDr. Zuzana Hajduová, PhD., Ing. Katarína Procházková, PhD., Ing. Peter Štetka, PhD.

STU: Ing. Štefan Čerba, PhD., doc. Ing. Branislav Vrban, PhD.

Proofreading: Bc. Doty Benjamin Warren

Publisher: Vydavateľstvo Ekonóm, Dolnozemská cesta 1, 852 35 Bratislava, Slovakia (EU)

Year: 2026

ISBN: 978-80-225-5315-5

FOREWORD

The intersection of nuclear science and business management represents one of the most strategically significant and intellectually demanding fields of our time. As the world navigates its energy transition and reckons with both the promise and the complexity of nuclear power, the need for professionals who can bridge technical expertise with managerial acumen has never been greater.

This study text has been developed as a resource for candidates seeking admission to the joint Master's degree programme in Management in Nuclear, offered by the STUBAxEUBA Consortium — a partnership between the Slovak University of Technology in Bratislava (STU) and the Bratislava University of Economics and Business (EUBA). The programme is designed to produce graduates equipped not only with a deep understanding of nuclear physics and reactor technology, but also with the business, financial, and organisational skills necessary to lead in the energy sector.

The material presented here is intentionally interdisciplinary. *Part One* covers the foundational principles of nuclear physics — from atomic structure and radioactivity to reactor systems, the nuclear fuel cycle, radiation protection, and prospective Generation IV technologies. *Part Two* addresses the economic and managerial dimensions of running complex organisations, including financial analysis, corporate capital management, enterprise typology, cost analysis, market theory, and the full spectrum of managerial functions from planning and organising through to leadership and communication.

Prospective students are expected to demonstrate competency in both domains during the entrance examination. This guide is therefore structured to reflect that dual requirement, providing a systematic overview of the key concepts, analytical frameworks, and applied examples relevant to each area. The inclusion of nuclear-sector illustrations throughout the managerial chapters reflects the programme's commitment to contextualised, practice-oriented learning.

We encourage candidates to engage critically with the material — not merely to memorise facts, but to develop an integrated understanding of how technical and economic reasoning interact. The challenges of managing a nuclear power plant, evaluating the economics of small modular reactors, or navigating regulatory frameworks require precisely this kind of synthesis.

We wish all candidates success in their preparations and look forward to welcoming the next generation of nuclear management professionals.

Editors
STUBAxEUBA Consortium, Bratislava, 2026

CONTENTS

PART ONE

Nuclear Physics and Technology

CHAPTER 1: THE ATOMIC NUCLEUS

An atom is the basic unit of matter that consists of neutrons and protons. The number of protons in an atomic nucleus corresponds to the nuclear charge Z, which we also call the **atomic number** or **proton number**, and it is identical to the element's position in the **Mendeleev periodic table of chemical elements**. The number of nucleons (protons and neutrons) in the nucleus is denoted by A and is called the **mass number** or **nucleon number**, because it approximately corresponds to the mass of the nucleus. The number of neutrons in the nucleus is denoted by N and can be calculated as the difference between the mass number and the atomic number:

$$N = A - Z \tag{1.1}$$

A nucleus with a specific number of protons and neutrons is called a **nuclide**. Nuclei with different numbers of protons but the same number of nucleons are called **isobars**, while nuclei with different numbers of protons but the same number of neutrons are called **isotones**. Nuclei of the same element (same Z) with different numbers of neutrons (different A) are called **isotopes,** like different isotopes of uranium. Nuclei with the same numbers of protons and neutrons but existing in different **isomeric states** are called **isomers**.

All atoms have approximately the same size, regardless of the number of electrons in their shells—about **1–2 angstroms (Å)**, where $1\ \text{Å} = 10^{-10}$ m. The atomic nucleus is about **four orders of magnitude smaller**, and its size is expressed in **femtometres (fm)**, where $1\ \text{fm} = 10^{-15}$ m.

The radius of the nucleus depends on the number of nucleons it contains, ranging from about **8 fm** for light nuclei such as carbon to **30 fm** for heavy nuclei such as lead. All experimental methods, however, show that the **volume of the nucleus is directly proportional to the number of nucleons** it contains, i.e., to the mass number A.

If we denote the nuclear radius by R, its volume can be expressed as:

$$V = \frac{4}{3}\pi R^3 \approx kA, \tag{1.2}$$

where k represents the proportionality constant between the nuclear volume and the number of nucleons. Therefore, the nuclear radius can be expressed by the general relation:

$$R = R_0\, A^{1/3} \tag{1.3}$$

where R_0represents a characteristic length on the order of a femtometer, determined experimentally. Since the nucleus consists of particles in motion, its surface is “diffuse” due to the laws of quantum mechanics. The Heisenberg uncertainty principle states that certain pairs of physical quantities, such as the position and momentum of particles, cannot be simultaneously determined with precision better than the limit $h/2\pi$. This leads to different, although order-of-magnitude similar, values of R_0.

To estimate the nuclear radius R for a nucleus containing A nucleons, a semi-empirical relation may be used:

$$R = 1.25 \times 10^{-15} A^{1/3} (m) \tag{1.4}$$

One of the most important properties of the atomic nucleus is its mass M, because despite its extremely small size relative to the atom, it contains nearly all the atom's mass. For practical reasons, nuclear physics does not usually employ SI base units; instead, it uses the **atomic mass unit (amu)**. In 1803, *J. Dalton* proposed using the mass of the hydrogen atom; later, *W. Ostwald* preferred $1/16$ of the oxygen atom. However, after the discovery of isotopes in 1912, these definitions proved inadequate. Since 1961, the **unified atomic mass unit** u has been used, defined as $1/12$ of the mass of a carbon-12 atom in its ground state: u = 1.660539×10^{-27} kg.

The Binding Energy of the Nucleus

The binding energy of the nucleus is the result of the competition between the attractive nuclear forces acting among nucleons and the electrostatic repulsion between the protons. The nuclear binding energy E_B is defined as the energy required to separate a nucleus of mass $M(A,Z)$ into individual nucleons with zero kinetic energy:

$$E_B + M(A,Z)c^2 \rightarrow Zm_pc^2 + (A-Z)m_nc^2 \tag{1.5}$$

The binding energy is determined via the **mass defect**, which is the difference between the mass of a nucleus and the sum of the masses of its constituent free nucleons. Because the masses of the proton and neutron are known with high precision, we can compare the mass of the nucleus with the sum of nucleon masses. Empirically, the nuclear mass $M(A,Z)$ is always **smaller** than the sum of the proton and neutron masses. The mass defect is therefore positive:

$$B = Zm_p + (A-Z)m_n - M(A,Z) \tag{1.6}$$

Since tabulated data typically list **atomic masses** rather than nuclear masses, it is convenient to rewrite eq. (1.6) as follows:

$$B = ZM_{at}({}^1_1H) + (A-Z)m_n - M_{at}(A,Z) \tag{1.7}$$

where $M_{\text{at}}({}^1_1\text{H})$is the atomic mass of hydrogen and $M_{\text{at}}(A,Z)$is the atomic mass of the nuclide of interest. This form differs from (1.6) by adding and subtracting Z electron masses, while neglecting electron binding energies (which are on the order of tens of eV).

The total binding energy is then:

$$E_B = Bc^2 \tag{1.8}$$

This represents the energy required to separate the nucleus into individual nucleons—or equivalently, the energy released when the nucleus is formed. The binding energy increases with the total number of nucleons (see Figure 1.1). For example:

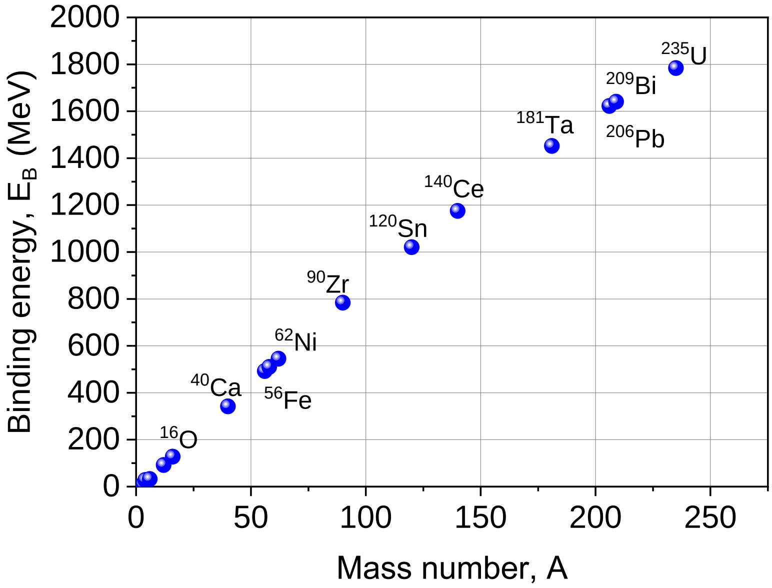
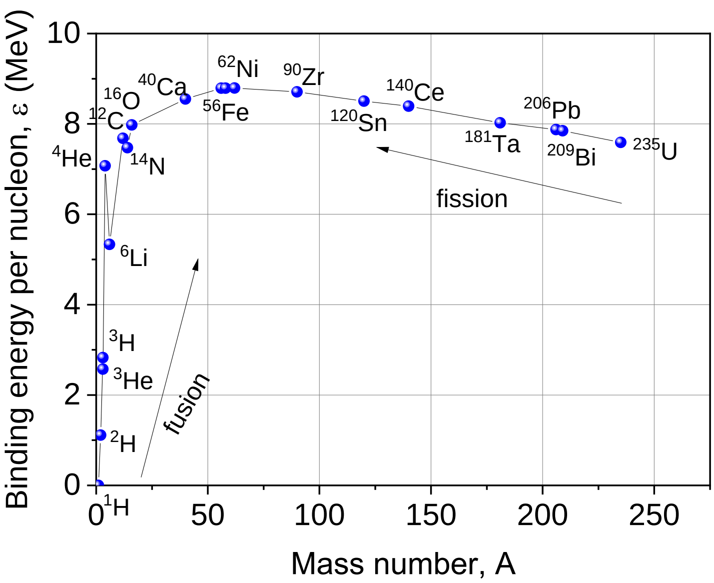


Figure 1.1: The binding energy of selected nuclides as a function of mass number A.

One of the most important nuclear quantities is the **binding energy per nucleon**:

$$\varepsilon = \frac{E_B}{A} = \frac{Bc^2}{A} \tag{1.9}$$



Nuclide	ε (MeV)
^{1}H	0.0000
^{2}H	1.1123
^{3}He	2.5727
^{3}H	2.8273
^{4}He	7.0739
^{6}Li	5.3324
^{12}C	7.6801
^{40}Ca	8.5513
^{56}Fe	8.7903
^{62}Ni	8.7945
^{209}Bi	7.8481

Figure 1.2: The dependence of the binding energy per nucleon on the mass number A.

Figure 1.2 illustrates the dependence of the binding energy per nucleon on the mass number A of its nucleus. Several important conclusions follow:

- The average binding energy per nucleon is approximately constant, about 8 MeV, for medium-heavy and heavy nuclei. This independence from the total number of nucleons reflects the **saturation property of nuclear forces**, which are very short-ranged and allow each nucleon to interact only with its nearest neighbours.
- From a global perspective, the average binding energy as a function of the nucleon number initially increases steeply, then more slowly, until it reaches a maximum in the region of iron and nickel nuclei. The maximum value, $\varepsilon_{\max} \approx 8.7945$ MeV at $A \approx 62$ for $^{62}_{28}Ni$, is followed by a gradual decrease to approximately 7.6 MeV for the heaviest nuclei. This global maximum corresponds to medium-heavy nuclei, which are the most stable, since the largest amount of energy is required to remove their nucleons.
- If, during a nuclear reaction, nuclei with lower average binding energy are transformed into nuclei with higher average binding energy, the final products have a lower total mass than the initial reactants. Consequently, energy is released equal to the mass defect of the reaction. The shape of the binding-energy-per-nucleon curve therefore explains why energy can be obtained from two seemingly opposite nuclear processes: **fusion** and **fission**. Light nuclei gain binding energy when fused, thus releasing energy, whereas for the heaviest nuclei, fission is energetically favourable and is accompanied by a release of nuclear energy (Fig. 1.2).
- The dependence also contains several **local maxima**, where the average binding energy of a given nuclide is significantly higher than that of its neighbours, for example, $^{4}_{2}He$. Such nuclei have completely filled their last occupied nuclear energy level by nucleons (closed shell), analogous to noble gases, which have completely filled electron shells in atomic structure. Both types are characterized by exceptionally high stability, the former in terms of nuclear decay, the latter in terms of chemical reactivity.

The Band of Stability

Nuclear stability refers to the ability of nuclei to resist changes in composition over time. From this perspective, all atomic nuclei can be classified as either **stable** or **radioactive**. Stable nuclei remain unchanged for an essentially unlimited time, while radioactive nuclei undergo spontaneous decay.

A remarkable property of all stable nuclei except hydrogen ($^{1}_{1}H$) is that they contain more neutrons than protons**,** or at most equal numbers of both. Figure 1.3 shows the dependence of the proton number as a function of neutron number for stable nuclei. The set of points corresponding to individual stable isotopes forms the **band of stability**. Nuclei lying outside the narrow band around this line are radioactive.

We observe that stable nuclei with $Z \leq 20$ typically have equal numbers of protons and neutrons ($Z = N$). However, as Z increases, the Coulomb repulsion among protons grows stronger, and nuclear forces require an excess of neutrons ($N > Z$) to maintain stability. Because nuclear forces saturate and act only between nearest neighbours, whereas Coulomb repulsion acts over the entire nucleus, a limit to stability exists. Beyond this point, even an excess of neutrons cannot ensure stability.

The last fully stable nuclide on the line of stability is ${}^{208}_{82}Pb$. Sometimes, ${}^{209}_{83}Bi.$ is also considered “practically stable,” although it undergoes alpha decay with an extremely long half-life of 2.01×10^{19}years. Beyond the stability boundary, nuclei undergo spontaneous decay.

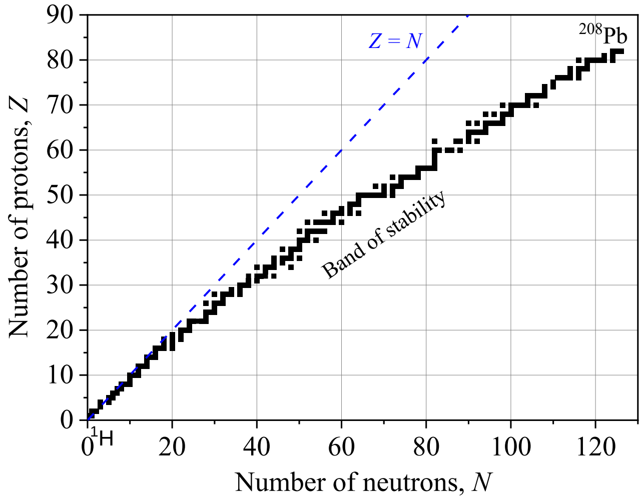


Figure 1.3: Band of stability showing the proton and neutron numbers of stable nuclei (black points).

Nuclear Forces

Atomic nuclei, despite the Coulomb repulsion between protons, exhibit stability, which means that in addition to the repulsive electric force, a very strong attractive force must also act between nucleons. As two protons approach each other, a strong nuclear attractive force is superimposed on the Coulomb repulsion; this force increases rapidly with decreasing distance and at approximately ~10^{-15} m exceeds the Coulomb force by a large margin. An equally strong interaction acts between a proton and a neutron, confirming that this force is not of electric origin.

The strong binding of nucleons indicates that **nuclear forces** operate within nuclei. This is the strongest known attractive interactions in nature. The shape of the nuclear potential energy shows that nuclear forces act only at very short distances, at which Coulomb repulsion becomes negligible. Nucleons reside at the bottom of a potential well whose depth and geometry correspond to a short interaction range, at most about 2 x 10^{-15} m.

Nuclear forces are neither electric nor gravitational; the neutrons have no electric charge, and gravitational interaction is roughly 10^{38} times weaker than required for nuclear stability. Nuclear forces exhibit **charge independence**, meaning they act similarly between pp, pn, and nn pairs.

They depend on the relative orientation of nucleon spins: parallel and antiparallel orientations give different force magnitudes, reflecting their **non-central** character. Magnetic interactions cannot account for nuclear forces, because the energy associated with magnetic moments of nucleons (~10^{-5} eV) is far too small compared to typical nuclear binding energies.

A characteristic feature of nuclear forces is **saturation**, each nucleon interacts only with its nearest neighbours. They are **exchange forces**, and according to current understanding, they arise from the exchange of mesons. A complete microscopic theory of nuclear forces is not yet fully established; many of their properties are known primarily from experiment.

The Stability of Nuclei

The stability of a nucleus reflects its ability to resist changes in composition. Nuclei are classified as **stable**, persisting indefinitely, or **radioactive**, undergoing spontaneous decay.

The shell model of the nucleus explains the higher stability (higher binding energy) of even-even nuclei (nuclei with an even number of protons and neutrons) compared to even-odd or odd-odd nuclei. In nature, we can find about 160 stable even-even nuclei, but only four stable odd-odd nuclei. For example, the nuclei $^{80}_{36}Kr$ and $^{80}_{35}Br$ are with the same number of nucleons, but krypton is an even-even nucleus and bromine is an odd-odd. We can see a significant difference in their binding energy, up to 2.501 MeV large, since bromine has an unpaired proton and neutron.

The nuclei, which have completely filled their last occupied nuclear energy level by nucleons (closed shell), are characterized by exceptionally high stability. The mean binding energy per nucleon exhibits pronounced maxima in those cases, and the numbers of protons or neutrons in such nuclei are called the **magic numbers:** Z or N or both = 2, 8, 20, 28, 50, 82, 126, 152.

The Radioactivity of Nuclei

Nuclei that undergo spontaneous transformation are called radioactive. During radioactive transformation, an atomic nucleus emits one particle (alpha, beta), several particles, or electromagnetic radiation (gamma), thereby losing its excitation energy or acquiring a configuration with greater stability.

CHAPTER 2: RADIOACTIVITY

Radioactivity is the process of spontaneous transformation of certain nuclei accompanied by the emission of subatomic particles or gamma radiation. Nuclei that undergo spontaneous transformation are called **radioactive**, while nuclei that do not undergo such transformations are called **stable**. During radioactive decay, the atomic nucleus emits one or several particles or electromagnetic gamma radiation, thereby releasing excess excitation energy or transitioning into a more stable configuration. The parent nucleus may transform into a nucleus of a different nuclide, which may involve a change in atomic number Z or mass number A. A radioactive substance is defined as a material containing one or more radionuclides whose activity is not negligible from the perspective of radiation protection.

Radioactivity was discovered by **Henri Becquerel** in 1896 when he observed an unknown invisible radiation emitted by uranium salts using a photographic plate. For the discovery of spontaneous radioactivity, he was awarded the **Nobel Prize in Physics in 1903**, together with Marie and Pierre Curie, who investigated the phenomenon of radiation and isolated two new radioactive elements, **polonium** and **radium,** from pitchblende extracted in Jáchymov. The term **radioactivity** was introduced by Marie Curie approximately four years after its discovery.

During radioactive decay, alpha particles (helium nuclei $^{4}_{2}He$), beta particles (electrons or positrons), or gamma photons are emitted. In some cases, other particles such as protons, neutrons, or nuclear fragments may also be emitted. A necessary, but not a sufficient condition, for radioactive decay is its **energetic favourability**. The mass of the radioactive nucleus must be greater than the total mass of the final nucleus plus the emitted particles. Therefore, the decay energy Q, manifested as the kinetic energy of the decay products, must be positive:

$$M_{\mathrm{i}}c^2 = M_{\mathrm{f}}c^2 + \sum M_p c^2 + Q \tag{2.1}$$

M_{i} – rest mass of the initial nucleus,
M_f– rest mass of the final nucleus,
M_{p}– rest mass of the emitted particles,
Q– decay energy,
c– speed of light in vacuum.

The decay energy Q corresponds to the reaction energy defined for nuclear reactions between two nuclei; hence, the same symbol Q is used. A radioactive decay is characterized by the type and energy of emitted particles, the lifetime of the nucleus, and, in multi-particle decays, by the angular correlations of the emitted particles.

Radioactivity is a **statistical process**. Identical nuclei decay over different time intervals. The probability of decay does not depend on how the nucleus was formed, how long it has existed, or on external conditions such as temperature or pressure. The decay probability is an intrinsic property of the nucleus and depends solely on its internal state. A radioactive decay can be described by the **mean lifetime** or by the **half-life**, defined as the time during which half of the radioactive nuclei of a given type undergo decay.

The range of half-lives observed in nature is extraordinarily large. Some alpha-emitting nuclides have half-lives of tiny fractions of a second (e.g., ${}^{212}_{84}Po$: 2.99×10^{-7}s), while others have half-lives of quadrillions of years (e.g., ${}^{144}_{60}Nd$: 2.29×10^{15} years $= 7.23 \times 10^{22}$s). Compared to microscopic timescales, these durations are immense. For example, the characteristic nuclear time (the time it takes a nucleon to traverse the nuclear diameter) is about 10^{-21}s. Thus, in the case of ${}^{238}_{92}U$, nucleons orbit the nucleus approximately 10^{38} times during its mean lifetime before a decay event occurs. This implies that there must exist physical mechanisms responsible for the long stability of the nucleus. The two primary reasons are:

1. The emission of heavy, positively charged particles (alpha particles, protons, deuterons, etc.) is strongly suppressed by the **Coulomb barrier**.
2. The weak interaction responsible for beta decay has a very low intensity compared with the nuclear force.

The Law of Radioactive Decay

Radioactive decay is a random process. The statistical quantity describing it is the **decay constant** λ, which expresses the probability of decay of a nucleus per unit time. For a large number $N_{\mathrm{R}}$of identical radioactive nuclei, the number of decays per unit time is:

$$A_{\mathrm{k}} = N_{\mathrm{R}}\lambda \tag{2.2}$$

The quantity A_k is called the **activity** of the radioactive substance. It represents the rate at which nuclei of the material undergo transformation.

$$A_{\mathrm{k}} = -\frac{dN_{\mathrm{R}}}{dt} \tag{2.3}$$

The negative sign is used because the number of radioactive nuclei decreases with time, whereas activity is defined as a positive quantity. The SI unit of activity is the **becquerel (Bq)**. An activity of 1 Bq means that one radioactive decay occurs per second. Before 1974, the unit **Curie (Ci)** was used, where:

$$1\ \mathrm{Ci} = 37\ \mathrm{GBq} \tag{2.4}$$

which corresponds to the activity of 1 gram of radium.

Because radioactive decay is spontaneous, the number of decays dN_{R} occurring during a time interval dt depends only on the number of undecayed nuclei N_{R} at time t and is proportional to the probability λdt that a given nucleus will decay during that interval:

$$dN_R = -N_R \lambda \, dt \tag{2.5}$$

Integrating this equation, assuming that at $t = 0$, the number of nuclei was N_{R0}, yields:

$$N_R = N_{R0} e^{-\lambda t} \tag{2.6}$$

It is the **Law of Radioactive Decay**, expressing the fact that the number of radioactive nuclei decreases exponentially with time (Figure 2.1).

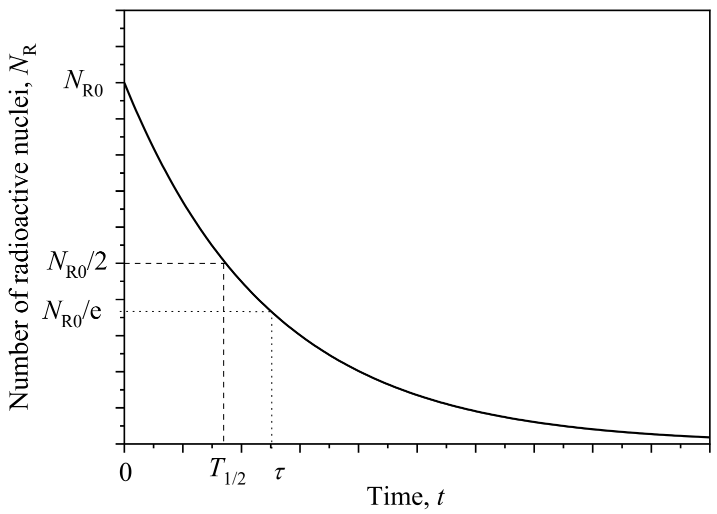


Figure 2.1: Graphical representation of the exponential decrease of radioactive nuclei with time — Law of Radioactive Decay.

Another characteristic quantity of radioactive nuclei is the **mean lifetime**, denoted by τ, defined as the weighted average of the lifetimes of nuclei of a given type:

$$\tau = \frac{1}{\lambda} \tag{2.7}$$

From the Law of Radioactive Decay, it can be shown that the mean lifetime is the time at which the original number of radioactive nuclei decreases by a factor of e:

$$N_R(\tau) = N_{R0} e^{-\lambda(1/\lambda)} = N_{R0} e^{-1} = \frac{N_{R0}}{e} \tag{2.8}$$

The time during which, on average, **half** of the radioactive nuclei decay (i.e., the time it takes the activity of a radioactive substance to drop to half its initial value) is called the **half-life**, denoted $T_{1/2}$. Starting from the decay law:

$$N_{\mathrm{R0}}/2 = N_{\mathrm{R0}}\, e^{-\lambda T_{1/2}}, 2 = e^{\lambda T_{1/2}}, T_{1/2} = \frac{\ln 2}{\lambda} \tag{2.9}$$

The relation between the mean lifetime and the half-life follows:

$$\tau = \frac{T_{1/2}}{\ln 2} = 1.44\, T_{1/2} \tag{2.10}$$

Because the activity of a radioactive substance is defined as the change in the number of radioactive nuclei over time, the decay law allows us to derive the empirical law for activity:

$$A_k(t) = -\frac{dN_{\mathrm{R}}(t)}{dt} = -\frac{d}{dt}(N_{\mathrm{R0}} e^{-\lambda t}) = \lambda N_{\mathrm{R0}} e^{-\lambda t} = \lambda N_{\mathrm{R}} \tag{2.11}$$

Considering that the initial activity is $A_{k0} = \lambda N_{\mathrm{R0}}$, the time dependence of the activity is as follows:

$$A_k(t) = \lambda N_{\mathrm{R0}} e^{-\lambda t} = A_{k0} e^{-\lambda t} (\mathrm{Bq}) \tag{2.12}$$

Graphical representations of the time dependence of activity (Figure 2.2) have the same exponential character as the time dependence of the number of radioactive nuclei shown in Figure 2.1.

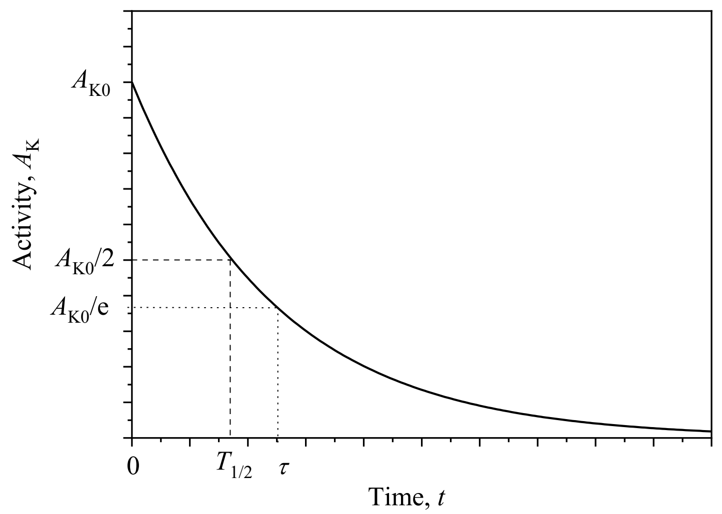


Figure 2.2: Graphical representation of the exponential decrease of the activity of radioactive material with time.

The Radioactive Decay of Nuclei

Radioactive transformations are spontaneous changes of unstable (radioactive) nuclei, the purpose of which is the release of excess nuclear energy. The nucleus releases energy by emitting ionising radiation, most commonly alpha, beta, or gamma radiation, or by emitting neutrons.

Alpha Decay (α)

Alpha decay is the spontaneous transformation of an alpha-radioactive nucleus accompanied by the emission of an **alpha particle**. Alpha particles are fast-moving helium nuclei, identified and named by **E. Rutherford** in 1903. An alpha particle consists of two protons and two neutrons. The general equation of alpha decay is:

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha \; ({}^{4}_{2}\mathrm{He}) \tag{2.13} $$

The nucleus ${}^{A}_{Z}X$ emits an α-particle and transforms into the nucleus ${}^{A-4}_{Z-2}Y$. In this nuclear reaction, an energy Q is released, known as the **alpha decay energy**. The new nucleus has two fewer protons and two fewer neutrons, and in the periodic table, it will appear two positions to the left of the original element. The atomic number of the daughter nucleus is reduced by two (to $Z-2$) and the mass number is reduced by four (to $A-4$). These rules are described by the **Fajans–Soddy radioactive displacement law**, formulated by *K. Fajans* and *F. Soddy* in 1913. The law makes it possible to predict the position of nuclei after radioactive decay and thus determine the chemical properties of the daughter element.

An example of alpha decay is the following nuclear reaction:

$$ {}^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + \alpha \; ({}^{4}_{2}\mathrm{He}) \tag{2.14} $$

Alpha decay occurs predominantly in **heavy nuclei** ($Z > 82$), for example ${}^{222}_{86}\mathrm{Rn}$, ${}^{226}_{88}\mathrm{Ra}$, ${}^{241}_{95}\mathrm{Am}$ ..., as well as in a small group of nuclides in the region of the rare earth elements: ${}^{144}_{60}\mathrm{Nd}$, ${}^{147}_{62}\mathrm{Sm}$, ${}^{152}_{62}\mathrm{Gd}$, ${}^{174}_{90}\mathrm{Hf}$, ${}^{190}_{78}\mathrm{Pt}$. The cause of alpha radioactivity in heavy nuclei is the imbalance between attractive nuclear forces among nucleons (strong residual interaction) and the repulsive electrostatic forces between protons. Attractive nuclear forces are short-ranged, and the total binding energy of the nucleus is roughly proportional to the mass number A. The repulsive Coulomb forces among protons have an unlimited range, and their total destabilizing contribution is roughly proportional to Z^2. In nuclei with more than 82 protons, the repulsion is so strong that short-range nuclear forces can no longer compensate for it. Alpha decay thus serves as a mechanism by which the nucleus increases its stability by reducing its size.

Beta Decay (β)

Beta decay is the spontaneous transformation of a radioactive nucleus accompanied by the emission of a β-particle or by electron capture. A beta particle is either an electron (β^-) or its antiparticle, the positron (β^+). Since electrons do not exist inside the nucleus, their emission is the result of the transformation of one of the nucleons, provided that the emitted electron or positron leaves the nucleus immediately. Beta decay is therefore an **intra-nucleon process**, by which the nucleus adjusts its neutron-to-proton ratio to achieve greater stability. It occurs throughout the periodic table for unstable isotopes.

There are **three types of beta decay**:

1. ***β^- decay,*** A neutron in the nucleus transforms into a proton, an electron, and an antineutrino:

$$\text{Reaction: } n \to p + \beta^- + \overline{\nu_e} \tag{2.15}$$

$$\text{General equation: } {}^{A}_{Z}\mathrm{X} \to {}_{Z+1}^{\;\;A}\mathrm{Y} + \beta^- + \overline{\nu_e} \tag{2.16}$$

$$\text{Example: } {}^{12}_{5}\mathrm{B} \to {}^{12}_{6}\mathrm{C} + e^- + \overline{\nu_e} \tag{2.17}$$

2. **β^+ decay**, A proton transforms into a neutron, a positron, and a neutrino:

$$\text{Reaction: } p \to n + \beta^+ + \nu_e \tag{2.18}$$

$$\text{General equation: } {}^{A}_{Z}\mathrm{X} \to {}_{Z-1}^{\;\;A}\mathrm{Y} + \beta^+ + \nu_e \tag{2.19}$$

$$\text{Example: } {}^{12}_{7}\mathrm{N} \to {}^{12}_{6}C + e^+ + \nu_e \tag{2.20}$$

3. ***Electron Capture***, A proton in the nucleus captures an orbital electron (usually from the K-shell) and transforms into a neutron and a neutrino:

$$\text{Reaction: } p + \beta^- \to n + \nu_e \tag{2.21}$$

$$\text{General equation: } {}^{A}_{Z}\mathrm{X} + \beta^- \to {}_{Z-1}^{\;\;A}\mathrm{Y} + \nu_e \tag{2.22}$$

$$\text{Example: } {}^{7}_{4}\mathrm{Be} + e^- \to {}^{7}_{3}\mathrm{Li} + \nu_e \tag{2.23}$$

Because the captured electron usually comes from the closest shell (the K-shell), electron capture is often referred to as **K-capture**. In all types of beta decay, the **mass number A remains constant**, while the **proton number** Z changes by ± 1.

Gamma Radiation (γ)

All stable nuclei generally reside in their lowest energy state. If a nucleus is in an excited state, typically after a preceding alpha or beta decay in which the emitted particles do not carry away the entire excitation energy, it may undergo a transition to a lower energy level by emitting a **gamma photon**. Thus, many nuclear transformations (alpha decay, beta decay) are frequently accompanied by the emission of gamma radiation.

Gamma emission can only occur if the nucleus is in an excited state ${}^A_ZX^*$ and transitions to the lower state ${}^A_ZX$.

$$ {}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X}^* \rightarrow {}^{\mathrm{A}}_{\mathrm{Z}}\mathrm{X} + \gamma \tag{2.24} $$

In this process, neither the mass number nor the atomic number of the nucleus changes.

A nuclear transition may be **single step**, when the nucleus emits one gamma photon, or **cascade**, when the transition to the ground state occurs through a sequence of gamma emissions (Figure 2.3).

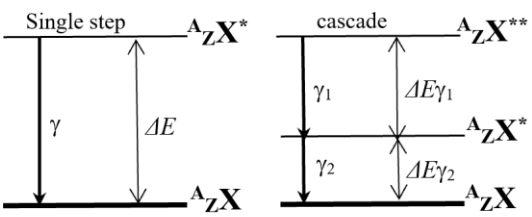


Figure 2.3: Single step and cascade transitions of a nucleus to a lower energy state accompanied by gamma emission.

The energy of gamma radiation E_γ equals the difference between the nuclear energy levels:

$$ \Delta E = E_1 - E_2 \tag{2.25} $$

The gamma-photon energy spectrum from a source is **discrete**. An example is the spectrum of ${}^{60}_{27}Co$ shown in Figure 2.4. After beta decay to ${}^{60}_{28}Ni$, the daughter nucleus undergoes a cascade transition to the ground state, emitting two gamma photons with energies 1.17 MeV and 1.33 MeV (Figure 2.5). These photon types appear in the spectrum as two distinct peaks.

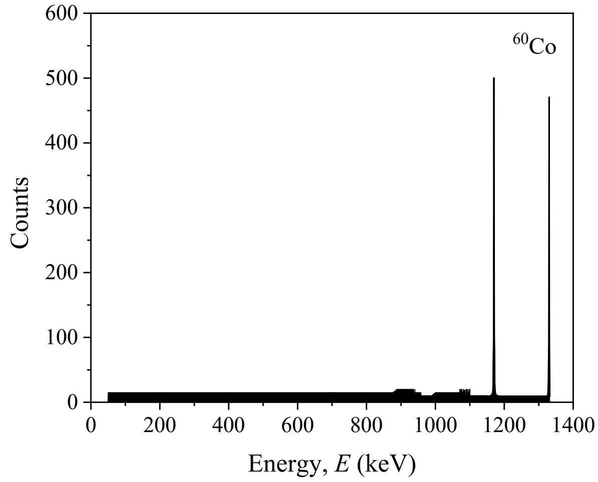


Figure 2.4: Gamma spectrum of $^{60}_{27}Co$.

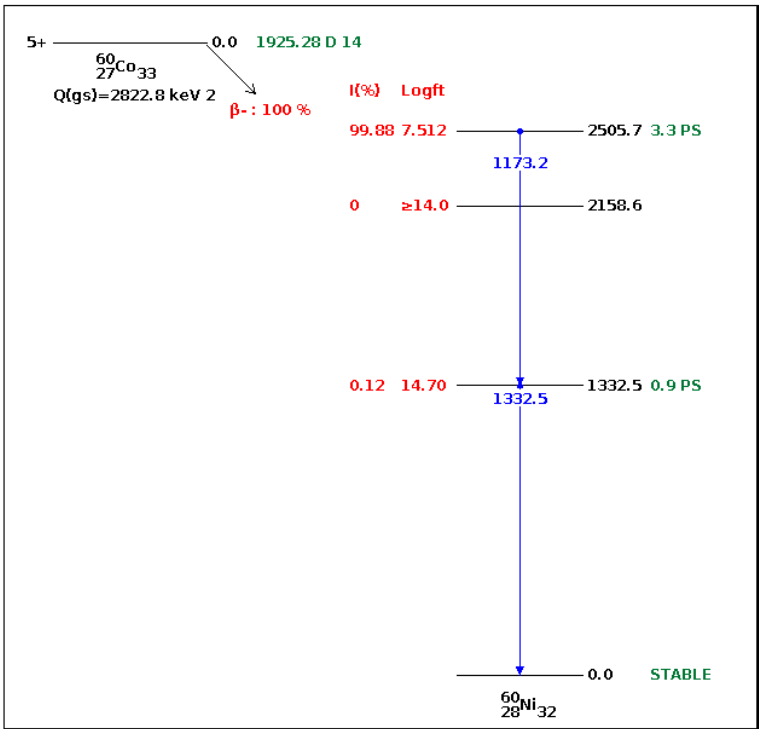


Figure 2.5: $^{60}_{27}Co$ decay scheme from the NuDat 3 database.

Gamma emission is **not the only mechanism** through which a nucleus may lose its excitation energy. The energy may also be released through **internal conversion**, a competing process to gamma emission. Electrons emitted in internal conversion arise due to electromagnetic interaction with the atomic electron shell. In internal conversion, an orbital electron is ejected with kinetic energy equal to the nuclear excitation energy minus the binding energy of the electron in the atom. Because internal-conversion electrons are monoenergetic, they can be distinguished from beta-decay electrons, which have a continuous spectrum.

CHAPTER 3: THE INTERACTION OF IONIZING RADIATION WITH MATTER

Understanding how ionizing radiation interacts with matter is essential in many fields of science and technology, including nuclear engineering, medical imaging, radiation protection, space research, and environmental monitoring. When radiation travels through any material (such as air, water, biological tissue, or detector media), it transfers part or all its energy to the atoms and molecules in that material. This energy transfer leads to ionization, excitation, or structural changes, and it determines both the useful applications and the potential risks associated with radiation. This chapter provides an overview of the basic types of ionizing radiation and the principal mechanisms through which they interact with matter.

The Classification of Ionizing Radiation

Ionizing radiation refers to any form of radiation that has enough energy to remove electrons from atoms or molecules, thereby creating ions. This distinguishes it from non-ionising radiation such as visible light or radio waves.

Ionizing radiation can be divided into four main categories, based on fundamental differences in its interaction with matter:

- Heavy charged particles: α-particles, protons, heavy ions.
- Light charged particles: electrons, positrons (β^- and β^+ radiation).
- Photons: γ-rays, X-rays (characteristic, bremsstrahlung), annihilation photons.
- Neutrons: fast, epithermal, and thermal neutrons.

Each group has one typical representative particle, which is very often used to distinguish different types of ionizing radiation.

Alpha particles (α) represent heavy charged particles. They are fast-flying helium nuclei (consisting of two protons and two neutrons). They:

- ionise atoms along their path through matter,
- have straight trajectories,
- are limited in their penetration ability, depending on their energy.

Beta particles (β^- and β^+) represent light charged particles. Beta radiation consists of electrons (β^-) or positrons (β^+) emitted during nuclear decay. Beta particles:

- are highly scattering,
- are more penetrating than alpha particles (they can travel several tens of centimetres in air and can be stopped by thin metal sheets),
- can have longer and irregular paths in matter than alphas (Their trajectory is not straight because they undergo strong deflections during collisions with atomic electrons.).

Their biological effects and detection depend strongly on their energy.

Gamma rays (γ) represent high-energy photons. They are forms of electromagnetic radiation with high energy. They:

- have very strong penetration ability
- interact with a certain probability.

Dense materials such as lead or thick concrete are required to attenuate them. Gamma radiation is produced during the transition of an atomic nucleus, while X-rays are created in an atomic shell and arise from electronic transitions or deceleration of charged particles.

Neutrons are uncharged particles with mass, which can be found in the nuclei of atoms. They interact very differently from charged particles:

- they do not cause ionisation directly,
- they interact mainly with atomic nuclei,
- they are highly penetrating.

Special shielding materials (water, polyethylene, or concrete) are used to slow down or absorb neutrons.

The Interaction of Ionizing Radiation with Matter

The type and probability of the interaction with matter depend on both the radiation and the matter. The main influencing properties of the interaction from a radiation point of view are:

- particle energy,
- particle electric charge,
- particle rest mass.

From a matter’s perspective, it is:

- material density,
- material elemental composition,
- mean ionization potential of material atoms.

According to two important particle parameters, the electric charge and the rest mass, we distinguish four main groups of ionizing particles, which fundamentally differ in their interaction with matter. Their interactions are described below.

The Interaction of Heavy Charged Particles with Matter

Heavy charged particles interact with matter mainly through Coulomb forces between the particle and the atomic electrons of the material. As a result of these interactions, the particle gradually loses its kinetic energy, and the atoms are either ionized or excited. The process repeats with atoms along the particle’s trajectory until the particle loses all its kinetic energy and stops. The distance a particle travels before coming to a complete stop is called the range, and it depends on the particle's kinetic energy, its mass, and its charge, as well as on the material it traverses. The particle deviates slightly from its original path because, compared to electrons, it has a significantly greater mass. Therefore, the path of heavy charged particles in matter is practically straight (Figure 3.1 left).

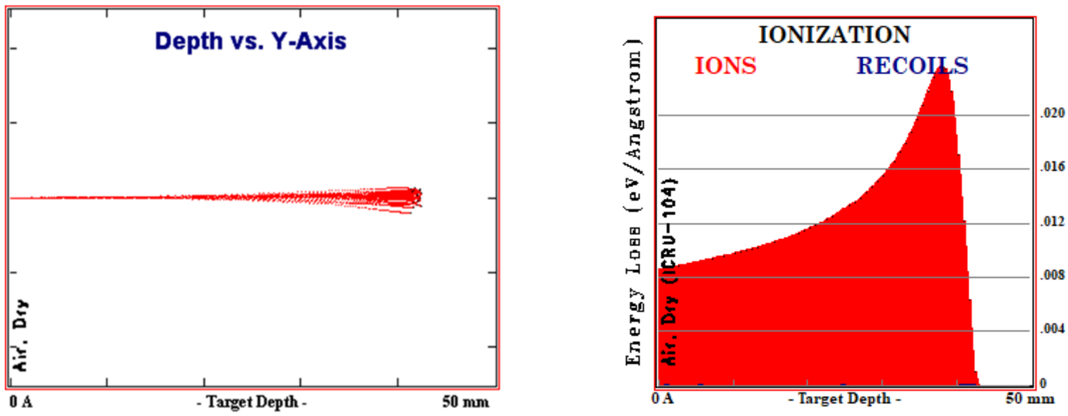


Figure 3.1. SRIM simulated trajectories of heavy charged particles (α, 5.5 MeV) in air (left). The energy deposition by α-particles of 5.5 MeV energy in the air. The α-particles deposit energy over a short, well-defined range (< 5 cm) with a Bragg peak, SRIM simulation (right).

The energy-losses of a particle due to the ionization of matter atoms are called ionization losses. Ionization losses of a charged particle are proportional to the square of the particle's electric charge (ze) and to the electron number density of material (n_e), but inversely proportional to the square of the particle's velocity (v). The mean energy loss per distance travelled of heavy charged particles traversing matter describes the Bethe-Bloch formula, with ε_0, the permittivity of the vacuum, m_e, the rest mass of the electron, I, the mean excitation energy of the material atoms, e, the electron charge and $\beta = \frac{v}{c}$ with c, the velocity of light in the vacuum:

$$\left(-\frac{dE}{dx}\right)_{ion} = \left(\frac{1}{4\pi\varepsilon_0}\right)^2 \frac{4\pi}{m_e} \frac{(\boldsymbol{ze^2})^2 \boldsymbol{n_e}}{\boldsymbol{v^2}} \left[\ln \frac{2m_e v^2}{\mathrm{I}(1-\beta^2)} - \beta^2\right] \tag{3.1}$$

This means that a particle with a higher velocity (greater kinetic energy) has smaller energy losses than a slower particle. The same applies to a particle passing through a material. As a particle passes through a material, its speed decreases, and energy losses increase. Consequently, the particle slows down faster. Its energy losses will increase sharply until the particle stops. When displaying the dependence of energy losses on the depth of particle penetration, this phenomenon appears as a Bragg peak, see Figure 3.1 right.

The Interaction of Light Charged Particles with Matter

The light charged particles interact with matter in a similar way to heavy charged particles. However, they are much lighter, so they undergo frequent scattering and produce more diffuse, irregular tracks (Figure 3.2 left). In their case, the term range is not used, but a practical range is more suitable. The practical range is the average length of the line between the beginning and end of the particle trajectory. It is not the length of the distance particles travel in the material before stopping, but the depth to which they reach in the material.

Moreover, besides the ionization and excitation of matter, another interaction mechanism plays a role in the case of beta radiation. It is their braking in the field of matter-nuclei accompanied by production of bremsstrahlung radiation (X-rays). The energy losses for braking are called radiative losses. They are higher for particles with higher kinetic energy E and in absorbing materials with higher atomic number Z and higher atomic density n:

$$\left(-\frac{dE}{dx}\right)_{rad} = \frac{EnZ(Z+1)e^4}{\mathrm{m_e c^2}} \frac{1}{137} \left(4 \ln \frac{2\mathrm{E}}{m_e c^2} - \frac{4}{3}\right) \tag{3.2}$$

The radiative losses dominate for electrons with high kinetic energy and in the case of their penetration through a material with a high atomic number. The ratio of radiative and ionization losses for an electron with kinetic energy $E(MeV)$ in a material with atomic number Z is expressed by the semi-empirical formula:

$$\frac{\left(-\frac{dE}{dx}\right)_{rad}}{\left(-\frac{dE}{dx}\right)_{ion}} = \frac{E(MeV).Z}{800} \tag{3.3}$$

The light charged particles exhibit two main types of energy losses during their penetration of matter:

- ionizing losses (ionisation and excitation of atoms),
- radiative losses (bremsstrahlung production).

Light charged particles do not form a Bragg peak in energy-loss distribution; instead, their energy is released to the material and decreases more gradually with material depth (Figure 3.2 right).

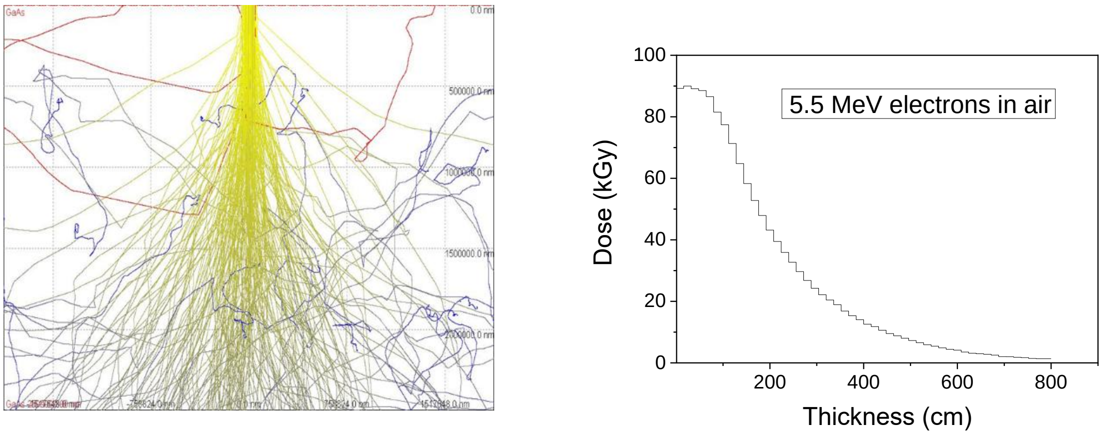


Figure 3.2: CASINO simulated trajectories of light charged particles (5 MeV β-particles) in GaAs (left). Energy deposition by 5.5 MeV β-particles as a function of penetration depth in the air, with long (> 6 m), more gradual decrease, simulation in ModePEB (right).

The Interaction of Gamma Rays with Matter

Gamma rays are electromagnetic waves or photons of high energy. Unlike charged particles, the photons have no charge and no rest mass. Since photons are not subject to electromagnetic interactions (they have no electric charge) or strong nuclear interactions, their interactions will take place over short distances. They do not interact continuously with matter but instead undergo discrete interactions at specific points with a certain probability. The energy of photon E_γ affects its interaction mechanisms and is given by the formula:

$$E_\gamma = h\upsilon = \frac{hc}{\lambda_\gamma} \tag{3.4}$$

where h is Planck's constant, λ_γ is a wavelength and υ a frequency of the electromagnetic wave of the photon.

- The characteristics of the interaction of photons with matter can be summarized in these points:
- The speed of gamma rays does not differ from the speed of light in a given medium.
- In the case of photons, there is no concept of maximum range in a substance, that is, the thickness of the substance beyond which none of the photons will penetrate.
- The intensity of gamma rays is reduced when passing through matter due to their absorption or scattering.

There are three basic mechanisms for the interaction of gamma rays with matter: the photoelectric effect, Compton scattering, and pair production. In addition to these, other mechanisms such as the nuclear photo-effect, Thompson, and Rayleigh scattering are also considered.

Photoelectric Effect: $\gamma + X \rightarrow X^{+} + e$

In the photoelectric effect, a photon transfers all its energy $E_{\gamma 0}$ to a bound electron, which is then ejected from the atom with kinetic energy E_{Ke} equal to the difference between the energy of the photon and the binding energy of the electron E_B.

$$E_{\gamma 0} = E_B + E_{Ke} \tag{3.5}$$

This interaction is most probable for low-energy photons and in materials with a high atomic number (Z).

If the ejected electron comes from an inner atomic shell, its vacancy is filled by an electron from a higher shell. The energy released during this transition is emitted as a photon whose energy equals the difference between the two energy levels. These photons are called fluorescent photons and belong to characteristic X-ray radiation.

If this emitted photon is subsequently absorbed by another atomic electron and causes its ejection, the released electron is called an Auger electron. Auger electrons are therefore produced when the atom releases its excess energy without emitting an external X-ray photon (Figure 3.3).

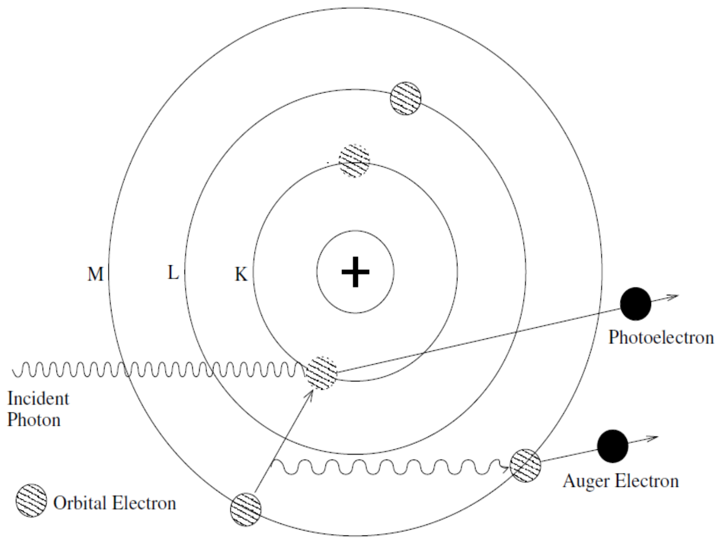


Figure 3.3: Illustration of the photoelectric effect with X-ray fluorescence and Auger electron emission.

When the photoelectric effect occurs inside the active volume of a detector, the emitted photoelectrons are fully absorbed and contribute a well-defined signal. In gamma spectrometry, this results in a sharp peak in the measured energy spectrum, known as the photopeak (Figure 3.3), since the detector registers only the electrons and records their deposited energy.

Compton Scattering: $\gamma_0 + X \rightarrow \gamma + X^{+} + e$

A photon with energy $E_{\gamma 0} = hv_0 = hc/\lambda_{\gamma 0}$ interacts with a weakly bound electron, transfers part of its energy to the electron, which is converted into the electron's kinetic energy E_{Ke} (we neglect the energy needed to release the electron from the bond) and the rest of the energy is emitted as a photon with energy $E_{\gamma} = hv = hc/\lambda_{\gamma}$, which is lower than the energy of the original photon $E_{\gamma} < E_{\gamma 0}$ and therefore the wavelength of the scattered photon will be greater (Figure 3.4).

$$E_{\gamma 0} = E_{\gamma} + E_{Ke} \quad (3.6)$$

This mechanism dominates at intermediate photon energies and is responsible for the continuum background observed in many gamma spectra, known as the Compton continuum. The upper limit of this continuum corresponds to the maximum energy that can be transferred to the electron and appears in the spectrum as the Compton edge (Figure 3.5).

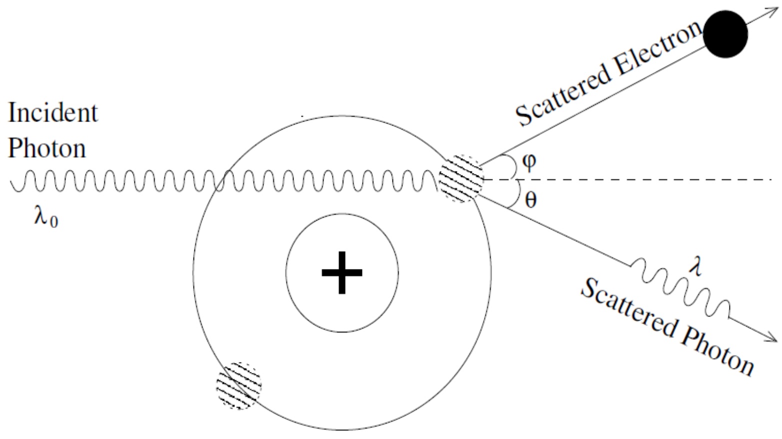


Figure 3.4: Illustration of Compton Scattering.

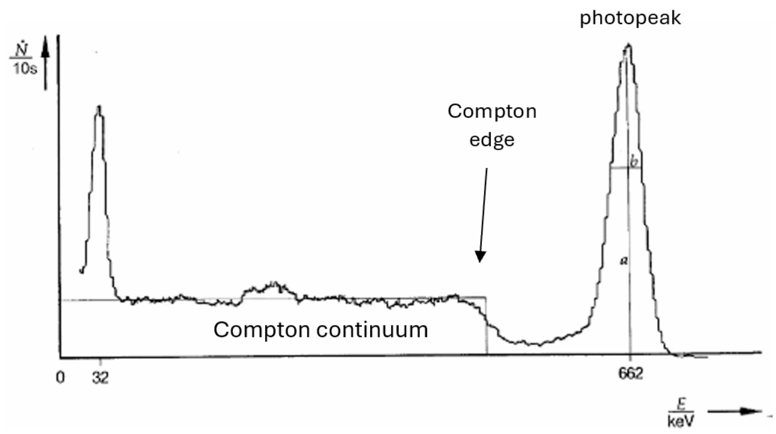


Figure 3.5: Gamma-ray spectrum of 137-Cs, showing the photopeak and the Compton continuum.

Electron-positron Pair Production: $\gamma + X \rightarrow e^{-} + e^{+} + X^{*}$

Pair production is the process by which a photon is converted into an electron-positron pair, i.e., energy is converted into matter. Given the fact that a photon has zero rest energy, and an electron and a positron are matter particles with a rest energy $E_{Re} = m_e c^2 = 511\ keV$, a necessary condition for pair production is that the interacting photon has an energy greater than the energy corresponding to the sum of the rest mass of the electron and the rest mass of the positron: 1.022 MeV. The second necessary condition for the interaction to occur is the presence of another heavy particle in the vicinity of the photon to maintain the law of conservation of momentum. The pair production occurs mainly in the vicinity of the nucleus of the atom (Figure 3.6), which will take over the back reflection during the emission of mass particles. The energy of a photon is converted into the electron and positron rest energies and their kinetic energies:

$$E_{\gamma 0} = 2m_{0e}c^2 + E_{Ke} + E_{Ke^+} \qquad (3.7)$$

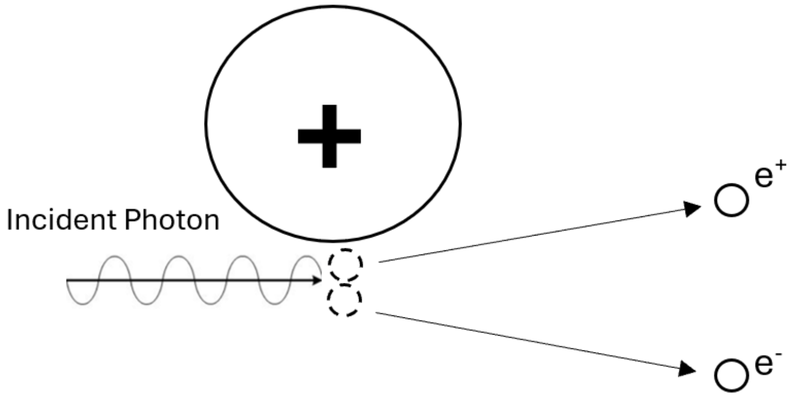


Figure 3.6: Illustration of electron–positron pair production.

Photon Attenuation Law (Absorption Law)

As a beam of monochromatic photons (X-rays, gamma rays) passes through a material, its intensity decreases because some photons are removed from the beam by interactions such as the photoelectric effect, Compton scattering, or pair production. For a uniform material, this decrease follows an exponential attenuation law:

$$I = I_0 e^{-\mu x} \tag{3.8}$$

where I is the photon intensity after passing through a thickness x, I_0 is the initial intensity of the beam, μ is the linear attenuation coefficient of the material, which describes the probability of photon interaction occurring per unit length within the absorber material. This law shows that the photon beam intensity drops exponentially with increasing thickness of the absorber.

The Interaction of Neutrons with Matter

Neutrons primarily interact with atomic nuclei. Having no charge, they can interact with any nucleus at any energy, but with varying probability. Neutrons undergo two main types of interactions with atomic nuclei, absorption and scattering.

Absorption (Neutron Capture)

During absorption, the interacting neutron is captured by the nucleus and create a compound nucleus, which transitions from an excited state to the ground state by the emission of a particle, multiple particles, or a gamma photon. If the excited compound nucleus after neutron capture is transitioning to the ground state only by the emission of a gamma photon, the process is called **radiative capture**. If the compound nucleus emits an alpha particle or a proton, it is transmitted into a new, radioactive isotope; the process is often called the **neutron activation**. If the compound nucleus breaks into two fragments of approximately equal mass, we call it **nuclear fission**.

Scattering

In case of the **elastic scattering**, the total kinetic energy of the system is conserved. It is only redistributed among the particles of the system. The neutron transfers part of its kinetic energy to the nucleus and changes the direction of its motion. The result is the deceleration of the neutrons. It is the dominant mechanism of interaction of fast (> 0.1 MeV) neutrons with matter from light nuclei (A < 20).

In case of the **inelastic scattering**, the neutron enters the target nucleus, and a compound nucleus is formed in an excited state, which emits a neutron with a lower kinetic energy. The nucleus then releases the energy difference by emitting a gamma photon.

The **neutron current density** J describes the net directional flow of monoenergetic neutrons through a unit of surface and time (neutrons.cm^{-2}·s^{-1}), decreases exponentially with depth x of material into which neutrons impinge:

$$J = J_0 e^{-\Sigma x} \tag{3.9}$$

where J_0 is the initial neutron current density and Σ is the **macroscopic cross-section** representing the probability that a neutron will undergo a reaction (absorption or scattering) per unit path length travelled in the material.

CHAPTER 4: NUCLEAR FISSION

When uranium is irradiated with neutrons, it has been found that several new radioactive nuclei with different half-lives are formed in the irradiated material. This fact was first observed by *E. Fermi* in 1934. However, he incorrectly assumed that the absorption of neutrons in different uranium isotopes resulted in the formation of radioactive nuclei with different half-lives. At the end of 1938, *O. Hahn* and *F. Strassmann* proved through precise radiochemical analysis that when uranium is irradiated with neutrons, elements from the middle of the periodic table are created. Physicists *L. Meitner* and *O. R. Frisch* explained this remarkable fact by proposing a hypothesis about the instability of heavy nuclei in relation to their shape, as a result of which the nucleus of a heavy element excited by neutron capture splits into two, three, or more parts. The nucleons of the original nucleus are distributed among these parts. The probability of a nucleus splitting into more than two parts is small, so we will not consider triple or multiple fission in the following. The fission process is schematically illustrated in Figure 4.1.

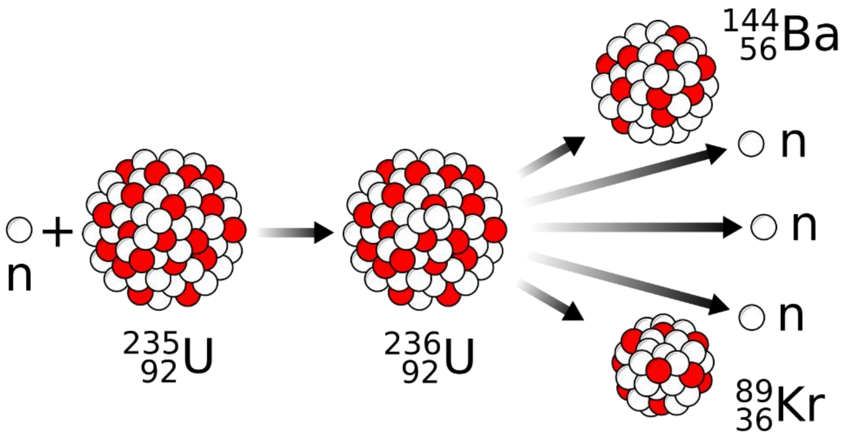


Figure 4.1: Diagram of nuclear fission.

The Fission Mechanism

The theory of **fission** was developed in 1939 by *N. Bohr*, *J. A. Wheeller* and *S. Frankel*, who analysed *L. Meitner* and *O. R. Frisch's* hypothesis on the instability of heavy nuclei in relation to their shape using a droplet model of the nucleus.

The similarity between nuclear matter and an ideal fluid lies in the following:

1. Both nuclear matter and ideal fluids are incompressible.
2. Their density does not depend on volume.
3. Their potential energy is directly proportional to their mass.
4. Surface forces act on the surface of the nucleus in a similar way to those acting on the surface of a liquid.

The fission process becomes energetically favourable (i.e., the amount of energy released Q>0) when the ratio $\frac{Z^2}{A} > 17$. The ration $\frac{Z^2}{A}$ is called the fission parameter. With the growth of the fission parameter the amount of energy released during fission Q also increases. The condition for the energy efficiency of fission is met for all nuclei located in the second half of the periodic table of elements. However, despite the energy efficiency, fission of all nuclei meeting this condition has not been observed experimentally. The fission has only been experimentally observed in the heaviest elements, starting with ${}^{232}_{90}Th$.

Next, the necessary energy conditions for fission will be examined. To this end, we will analyse the potential energy curve of two fission products. One of them is firmly connected to the origin of the coordinate system in Figure 4.2, and the second is approaching it. While the two products are far apart (r = ∞), their mutual potential energy is zero. As they gradually approach each other, the energy of Coulomb repulsion E_c increases inversely proportional to the distance until the moment when they touch each other; then nuclear forces, which are opposite to Coulomb forces, begin to act, causing the two fragments to merge and form the original nucleus. The course of the interaction energy between the two products is shown in Figure 4.2, where E_d is the initial energy of the nucleus, which is at rest and, according to the droplet theory of the nucleus, has a spherical shape (a) (Figure 4.3).

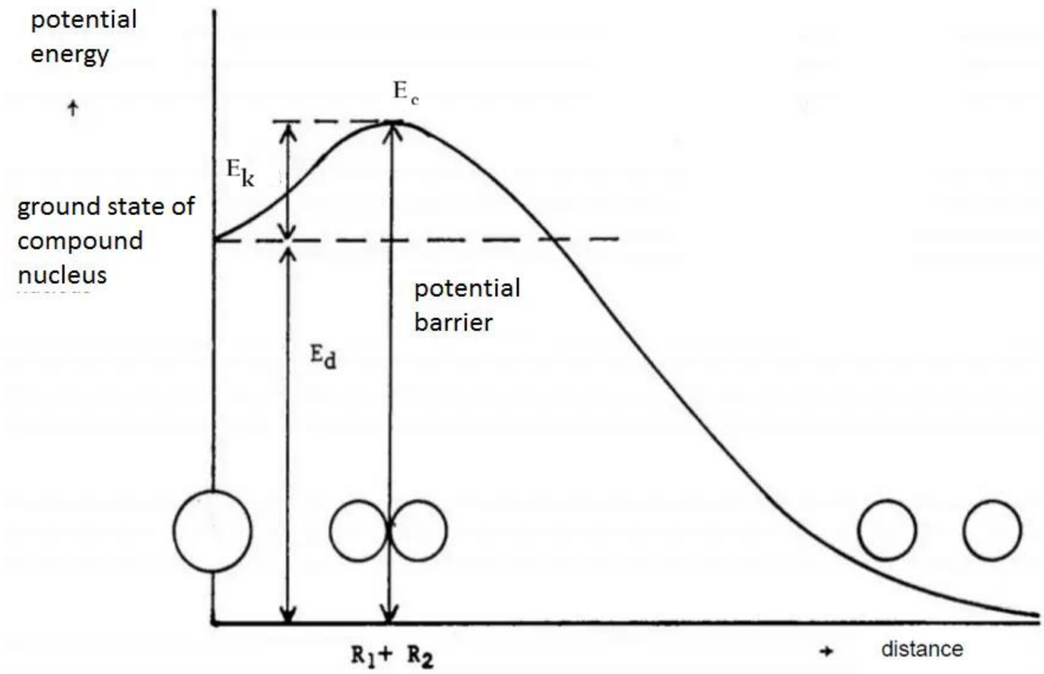


Figure 4.2: Change in potential energy depending on the distance between fission products.

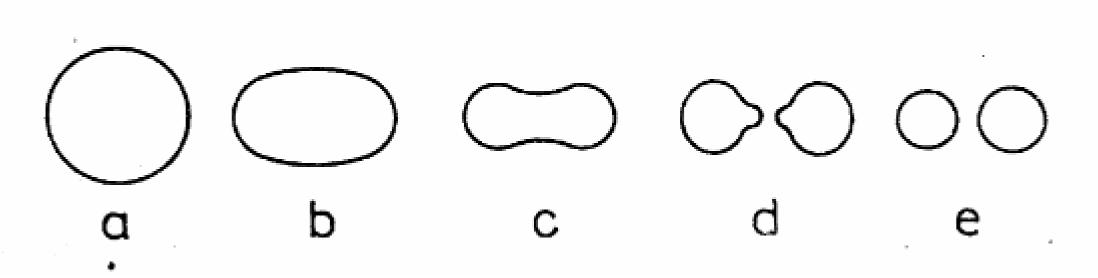


Figure 4.3: Schematic course of nuclear fission.

Let us assume that the nucleus is excited by neutron capture and begins to oscillate. Depending on the magnitude of the excitation energy, two cases are possible.

In the first case, if the **excitation energy is low**, the nucleus (a) will perform an oscillatory motion, therefore its shape will gradually change from a rotational ellipsoid (b) to a sphere. The size of the major and minor axes of the rotational ellipsoid will depend on the excitation energy. In this case, the nucleus oscillates until it emits the received amount of energy and returns to its initial position (a).

In the second case, if the **excitation energy is high**, the nucleus may exceed the critical point (c) of elastic deformation during the oscillation process, at which point it is no longer possible to return to its initial position. In this case, due to the action of large Coulomb repulsive forces between the created poles of the nucleus, the nucleus elongates increasingly until it splits into two parts. Surface forces quickly bring the new nuclei into a spherical state (d).

In Fig. 4.2, energy E_k represents the fission energy barrier. The value E_k is called activation energy and, by definition, it is equal to the energy that must be transferred to the nucleus. The magnitude of the activation energy determines the fission parameter; the greater $\frac{Z^2}{A}$ is than 17, the value of E_k is smaller, and for $\frac{Z^2}{A} = 49$, $E_k = 0$. This means that the nucleus with $\frac{Z^2}{A} = 49$ will split spontaneously, therefore such nuclei do not exist in nature.

For $\frac{Z^2}{A}$ less than 49, or for E_k close to zero, we speak of **spontaneous fission** of nuclei. The probability of spontaneous fission is lower, the lower the fission parameter is than 49. Spontaneous fission of uranium, which has a fission parameter equal to 36, occurs with very low probability. To induce prompt fission of a nucleus with a fission parameter lower than 49, a certain amount of energy E to the nucleus must be added, which is greater than or equal to the fission barrier $E_k \leq E$. This energy can be transferred to the nucleus in any way, e.g., by irradiation with photons, neutrons, etc. If the fission of the nucleus is induced by a neutron, then the condition for prompt fission has the following form:

$$E_n = e_n + T_n \geq E_k \qquad (4.1)$$

where e_n is the mean binding energy of a neutron in the nucleus, and T_n is the kinetic energy of the neutron relative to the target nucleus.

There can be two cases here:

1. $e_n \geq E_k$ - fission can be induced by thermal neutrons.
2. $e_n < E_k$ - fission can only occur if the kinetic energy of the neutron complies with the condition:

$$T_n \geq E_k - e_n \tag{4.2}$$

Experiments have shown that fission of ${}^{238}_{92}U$, and isotopes found in nature ${}^{232}_{91}Pa$ and ${}^{232}_{90}Th$, is only possible by the neutrons if their kinetic energy T_n is approximately equal to 1 MeV (fast neutrons), while the fission of the ${}^{235}_{92}U$ is carried out by **thermal neutrons**. It follows that the barrier isotope for the fission of isotopes ${}^{238}_{92}U$, ${}^{232}_{91}Pa$ and ${}^{232}_{90}Th$ is equal to:

$$E_k = e_n + T_n \approx (e_n + 1)MeV \tag{4.3}$$

and for the isotope ${}^{235}_{92}U$:

$$E_k < e_n \tag{4.4}$$

The difference in the fission conditions of two isotopes (${}^{235}_{92}U$, ${}^{238}_{92}U$) of the same element is explained by two reasons. Firstly, the height of the energy barrier E_k in the nucleus ${}^{235}_{92}U$ is lower than in the isotope ${}^{238}_{92}U$ because the fission parameter $\frac{Z^2}{A}$ is greater in ${}^{235}_{92}U$ than in ${}^{238}_{92}U$. Secondly, the average binding energy of the neutron absorbed by nucleus ${}^{235}_{92}U$ is greater than the binding energy of a neutron absorbed by nucleus ${}^{238}_{92}U$. The difference in binding energies can be explained by the fact that in the first case, a more stable even-even nucleus is formed by neutron capture ${}^{236}_{92}U$,while in the second case, an odd-even nucleus is formed ${}^{239}_{92}U$, which is less stable. Thus, in the transition from the isotope ${}^{238}_{92}U$ to isotope ${}^{235}_{92}U$, the fission barrier E_k decreases, and the average binding energy of the neutron e_n increases to such an extent that it exceeds the fission barrier. Therefore, only isotope ${}^{235}_{92}U$ is considered as fissile material.

Spontaneous Fission

Through a detailed study of the fission process of heavy nuclei in 1940, *K. Petrzhak* and *G. Florov* experimentally discovered spontaneous fission of heavy nuclei, caused by no external factors with a half-life elements in a wide range from ${}^{232}_{90}Th$ (Thorium) to ${}^{260}_{104}Ku$ (Kurchatovium) of decay half-life T_{sf} ranging from 10^{18} years to 380 µs. Spontaneous fission is a process of nuclear decay into two heavy fragments without the addition of external energy to the splitting nucleus. Fragments formed during spontaneous fission overcome the "fission barrier" through the tunnelling effect, see Figure 4.2, similar to alpha decay. The excitation energy in this case is less than E_k, where the fission products gain energy inside the splitting nucleus through the process of energy fluctuation.

The probability of spontaneous fission depends on the fission parameter $\frac{Z^2}{A}$ or the activation energy E_k. With increasing, $\frac{Z^2}{A}$ or decreasing value of E_k, the probability of spontaneous fission increases. The values of half-lives and decay constants of spontaneous fission of selected isotopes are given in Table 4.1. The index sf corresponds to the abbreviation of spontaneous fission.

Spontaneous fission produces similar products to those produced by the fission of heavy nuclei by thermal neutrons. The VVER 440 nuclear reactor uses 42t of UO_2 with an average enrichment of 4.87 % of the isotope ${}^{235}_{92}U$ in fresh fuel. The initial core loading for the first start-up can be characterized by 2.5×10^5 spontaneous fissions per second. The neutrons produced in this way are used to initiate a controlled fission chain reaction in the reactor core.

Table 4.1: Spontaneous fission characteristics.

Nucleus	Half-life of spontaneous fission T_{sf} [year]	Decay constant of spontaneous fission λ_{sf} [s^{-1}]
${}^{232}_{90}Th$	1.0×10^{18}	2.196×10^{-26}
${}^{233}_{92}U$	1.0×10^{15}	2.196×10^{-23}
${}^{234}_{92}U$	1.0×10^{16}	2.196×10^{-24}
${}^{235}_{92}U$	1.8×10^{17}	1.22×10^{-25}
${}^{237}_{92}U$	1.0×10^{16}	2.196×10^{-24}
${}^{238}_{92}U$	8.0×10^{15}	2.745×10^{-24}
${}^{239}_{92}U$	1.0×10^{14}	2.196×10^{-22}
${}^{239}_{94}Pu$	5.5×10^{15}	1.21×10^{-22}
${}^{241}_{94}Pu$	1.0×10^{11}	2.196×10^{-19}
${}^{242}_{96}Cm$	7.2×10^{6}	3.05×10^{-15}
${}^{253}_{99}Es$	7.0×10^{5}	3.14×10^{-14}
${}^{256}_{100}Fm$	3.9×10^{-4}	5.5×10^{-5}

Fission Energy

The energy Q released during fission is determined from the difference in mass between the initial nucleus M and the fission products (M_1 and M_2):

$$Q = (M_1 + M_2 - M)c^2 \tag{4.5}$$

The mass of the nucleus can be expressed as:

$$M = Zm_p + (A - Z)m_n - eA \tag{4.6}$$

where m_p and m_n are the masses of the proton and neutron, e is the average binding energy of a nucleon in the nucleus.

Substituting the last relation into the expression for fission energy, we obtain:

$$Q = e_1 A_1 + e_2 A_2 - eA = (\bar{e} - e)A \tag{4.7}$$

where $\bar{e} = \frac{e_1 A_1 + e_2 A_2}{A}$ is the mean binding energy of a nucleon in the nucleus of fission products.

Since the mean binding energy $\bar{e}$ of the fission products is approximately 0.8 MeV greater than the mean binding energy e of uranium, we can approximately determine the amount of energy released in a single fission event as follows:

$$Q = (\bar{e} - e)A = 0.8 \times 236 = 188\ MeV \tag{4.8}$$

In the following, we will assume that approximately **200 MeV** is released on average per fission event. During fission, the fission products carry away all the energy released during fission. The fission energy can then be characterized as the kinetic energy of the fission products Q_k and the energy of the radioactive decay of the fission products Q_d. The radioactive decay of the fission products includes beta decay, neutron emission, and accompanying gamma radiation.

The energy released during fission is distributed as follows:

Kinetic energy of fission products Q_k ≈	**160 MeV**
energy of radioactive decay Q_d ≈	40 MeV
of which:	
energy carried away by beta particles	8 MeV
energy carried away by gamma photons	15 MeV
energy carried away by neutrons	7 MeV
energy carried away by antineutrinos	10 MeV
Total	200 MeV

Since the fission products are nuclei from the middle of the periodic table of elements, which have a large electric charge, the loss of their kinetic energy per unit length will be very large. On average, fission products transfer all their kinetic energy to the environment in which they move along a path equal to approximately 10^{-6} m. Neutrons, beta particles, and gamma photons are also absorbed near the site of fission. Therefore, when determining the reactor's power, we assume that all the energy (reduced by the energy carried away by antineutrinos) released during fission is converted into thermal energy in the volume where fission occurs, i.e., in the nuclear reactor.

Fission Products

Analysis of the nuclear fission process using the liquid drop model of the nucleus suggests that the nucleus splits into two equal parts. However, this conclusion has not been confirmed experimentally. During the fission of the isotope $^{235}_{92}U$ by thermal neutrons, it was experimentally found that the most probable ratio of mass and atomic numbers of the nuclei produced during fission (fragments) is 2:3. We denote the heavier of the fragments as $M_T(Z_H,A_H)$ and the lighter as $M_L(Z_L,A_L)$. Absorption of thermal neutrons by the target nucleus results in the formation of $^{236}_{92}U$, and this nucleus fissions if condition (4.1) is met. The nuclear reaction can be written as follows:

$$
\begin{aligned}
235+1&=A_H+A_L \\
92+0&=Z_H+Z_L
\end{aligned}
\qquad (4.9)
$$

Using the conditions $A_L/A_H=2/3$ and $Z_L/Z_H=2/3$, individual values can be determined using equation (4.9) as follows:

$$
\begin{aligned}
A_H&=142 \qquad A_L=94 \\
Z_H&=55 \qquad Z_L=37
\end{aligned}
\qquad (4.10))
$$

These values lead to isotopes $^{142}_{55}Cs$ and $^{94}_{37}Rb$, which have stable isotopes: $^{133}_{55}Cs$, $^{87}_{37}Rb$ and $^{85}_{37}Rb$. The number of neutrons in each fragment is then:

$$N_H=A_H-Z_H=87 \quad \text{and} \quad N_L=A_L-Z_L=57 \qquad (4.11)$$

What has shown that the resulting nuclei have significantly more neutrons than protons. Nuclei with an excess of neutrons are unstable and undergo changes over time that lead to a reduction in the imbalance between neutrons and protons. In other words, nuclei increase their stability in this way.

The first of the nuclear processes that reduces the excess of neutrons is the direct emission of an integer number of neutrons, accompanied by gamma radiation. The average number of instantaneous neutrons υ_f produced during fission depends on the mass number of the fissioning element and the kinetic energy of the bombarding neutrons.

The new nuclei are not stable; they still have an excess of neutrons, but their excitation energy is less than the binding energy of the neutron, so further reduction of their excitation is only possible through gradual β^- decay until a stable nucleus is formed. For example, as a result of the fission of ^{235}U, the emission of prompt neutrons occurs with a 5.6% probability of isotope $^{135}_{52}Te$, which decays via β^- decay as follows:

$$^{135}_{52}Te \xrightarrow[\text{19 sec.}]{\beta^-} {}^{135}_{53}I \xrightarrow[\text{6.57 h}]{\beta^-} {}^{135}_{54}Xe \xrightarrow[\text{9.14 h}]{\beta^-} {}^{135}_{55}Cs \xrightarrow[2.6\text{x}10^6 \text{ years}]{\beta^-} {}^{135}_{56}Ba \qquad (4.12)$$

At the end of the decay chain is the isotope ${}^{135}_{56}Ba$, which is stable. As was noted that fission of ${}^{235}_{92}U$ by thermal neutrons produces fragments with asymmetrically distributed mass and atomic numbers. A detailed study of the fission of ${}^{235}_{92}U$ has shown that the probability of asymmetric fission is 600 times greater than the probability of symmetric fission (where both fragments have the same mass). Figure 4.4 shows the yield of fission products ${}^{235}_{92}U$ as a function of mass number A. The figure shows two maxima, one at A_L= 90÷100 and the other at A_H= 135 ÷145.

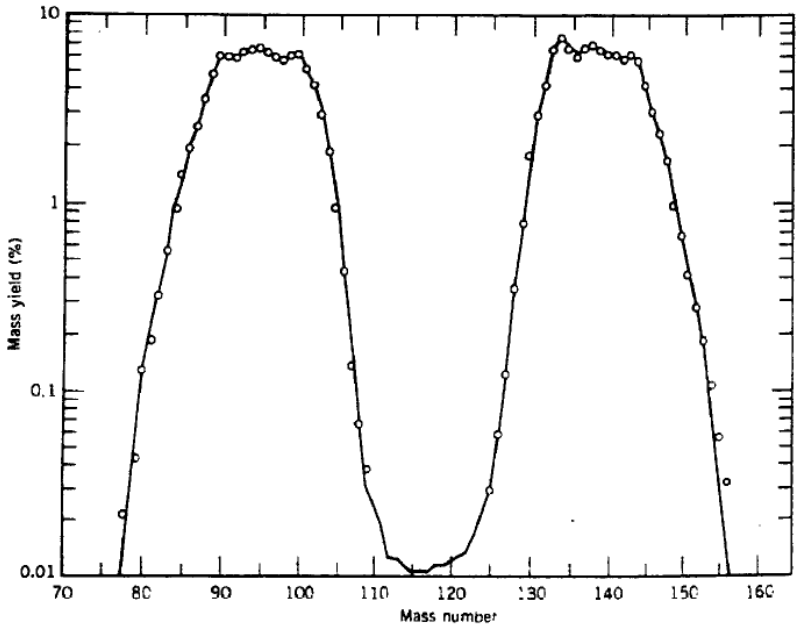


Figure 4.4: Yield of fission products depending on mass number A.

In addition to the fission of ${}^{235}_{92}U$, asymmetric fission of other heavy elements starting with ${}^{232}_{90}Th$ up to transuranic elements ${}^{239}_{94}Pu$ and ${}^{241}_{94}Pu$ was observed. The ${}^{235}_{92}U$ splits directly to 62 different fragments, which decay due to their instability. On average, these nuclei become stable after 2 - 3 successive β^- decays. In the core of a nuclear reactor in operation, approximately 200 different radioactive isotopes were observed. Therefore, "spent" fuel assemblies unloaded from the reactor are stored in specially prepared pools. In these so-called decay pools, the activity of the spent fuel gradually decreases to a level where the fuel can be transported in transport containers to a processing plant.

CHAPTER 5: NEUTRONS IN THE FISSION PROCESS

In the initial phase, the fission fragments contain many neutrons, and therefore, these nuclei are unstable. Transformation to a more stable state is accompanied by the emission of one, two, or more neutrons. The emission time of such neutrons is in the order of 10^{-14} to 10^{-12} s after the fragment formation. Due to the short time of the release, these neutrons are called the prompt neutrons.

Prompt Neutrons

The prompt neutrons are emitted in the energy range from 0.0253 eV to 10 MeV. The distribution of neutron emission depending on their energy is called the **Fission Neutron Spectrum,** see Figure 5.1, and is expressed empirically by the relationship:

$$n(E) = ce^{-E} \sinh \sqrt{2E} \tag{5.1}$$

In this equation, E is the kinetic energy of neutrons and c is a constant. The most probable energy of prompt neutrons is approximately 0.8 MeV. The average energy of prompt neutrons is $\bar{E}$ = 2 MeV.

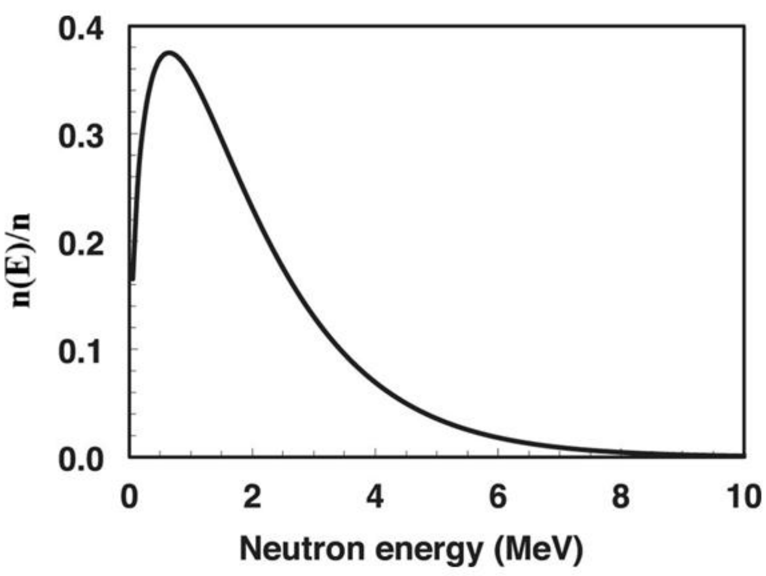


Figure 5.1: Fission Neutron Spectrum.

The prompt neutrons are generated by many daughter nuclei. Each of these nuclei can release one, two, or more immediate neutrons. On average, there are υ_f prompt neutrons per fission event. The value of υ_f varies depending on the fission nuclide and the energy of the neutrons that caused the fission; the higher the energy, the more neutrons are released per fission, i.e. $\upsilon_f = f(A, E_n)$.

For example:

$$^{235}_{92}U \qquad v^5_{fT} = 2.42 \qquad v^5_{ff} = 2.63$$

$$^{239}_{94}Pu \qquad v^9_{fT} = 2.87 \qquad v^9_{ff} = 3.12$$

$$^{238}_{92}U \qquad v^8_{fT} = 0 \qquad v^8_{ff} = 2.67$$

where the indices *fT* and *ff* denote the average number of neutrons from fission with thermal and fast neutrons.

Delayed Neutrons

The daughter nuclei of the fission fragments are formed after the fission and pass through several β^-decays. The nuclei formed in this way are usually in an excited state, where the excitation energy is lower than that of the original fragment. In some cases, the excitation energy may be greater than the binding energy of the neutron in the new nucleus. When these conditions are met, a neutron is emitted in a time interval of the order of 10^{-12} s, and the nucleus deexcites to its ground state, thus becoming stable.

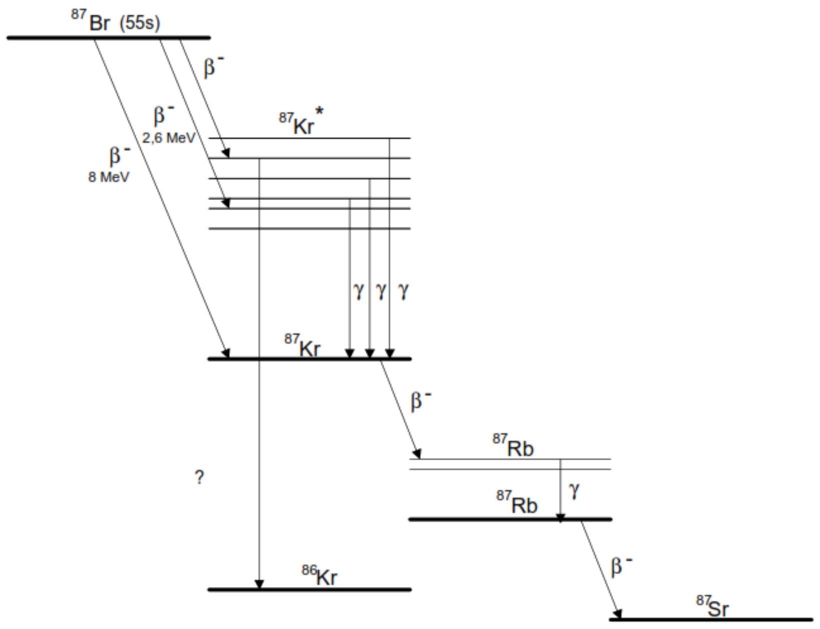


Figure 5.2: Mechanism of delayed neutron production with T = 55.6 s.

A specific example is the decay scheme shown in Figure 5.2. As a direct product of fission, the bromine nucleus $^{87}_{35}Br$ is created in an unstable state and decays. The product of β^-decay is the krypton isotope $^{87}_{36}Kr$ with several energy excited levels, depending on the distribution energy of the reaction between an electron (beta particle) and an antineutrino. This isotope of krypton has 36 protons and 51 neutrons in its nucleus. The fifty-first neutron has a binding energy of only 5.1

MeV. If ${}^{87}_{36}Kr$ is formed at an excited level of 5.4 MeV, this nucleus releases the excess energy by emitting a neutron with kinetic energy of 300 keV.

The neutrons produced in this way are delayed relative to the moment of fission by the lifetime of the precursor of the parent nucleus. We can say that the time it takes for a delayed neutron to be produced is equal to the lifetime of the precursor nucleus from which the excited parent nucleus that emitted the neutron originated. Depending on the time it takes for these neutrons to be produced, delayed neutrons have been divided into several groups. The parameters of the six-group representation of delayed neutrons are listed in Table 5.1. Each group is characterized by the time of origin (half-life) T(s) and the relative number of delayed neutrons (delayed neutron fraction) β_i, which are defined as follows:

$$\beta_i = \frac{\text{number of delayed neutrons in the i} - \text{th group}}{\text{umber of prompt } + \text{ delayed neutrons of all groups}}$$
$$\beta = \sum_{i=1}^{6} \beta_i \tag{5.2}$$

The total proportion of delayed neutrons depends on the fissile material used, and in the minority on the energy of the neutrons that caused the fission. For individual fissile materials such as ${}^{233}_{92}U$, ${}^{235}_{92}U$, ${}^{239}_{94}Pu$ and ${}^{241}_{94}Pu$, the proportion of delayed neutrons is equal to:

β^3 = 0.0021, β^5 = 0.0064, β^9 = 0.0021, β^1 = 0.0051.

The total delay time of these neutrons depends on the fissile material used and is expressed by the sum:

$$\sum_{i=1}^{6} \beta_i T_i \tag{5.3}$$

If the fissile isotope is ${}^{235}_{92}U$, the total delay time will be:

$$\left[\sum_{i=1}^{6} \beta_i T_i\right]^5 = 0.0942\ s \tag{5.4}$$

Note that the index in the upper right corner of the square bracket indicates that the given quantity belongs to the specified uranium isotope. For selected fissionable isotopes, Table 5.1 shows the distribution of the proportion and energy of delayed neutrons by individual groups.

Table 5.1: Delayed neutron fraction by group for selected isotopes.

Group	Half-life T(s)	Decay constant. λ (s^{-1})	$^{233}_{92}U$	$^{235}_{92}U$	$^{238}_{92}U$	$^{295}_{94}Pu$	Kinetic energy (keV)
1	55.6	0.0125	0.000224	0.000215	0.0002	0.00021	250
2	22.7	0.0305	0.000777	0.001424	0.0022	0.00182	460
3	6.22	0.1114	0.000655	0.001274	0.0025	0.00129	405
4	2.30	0.3014	0.000723	0.002568	0.0061	0.00199	450
5	0.61	1.1363	0.000133	0.000748	0.0035	0.00052	410
6	0.23	3.0137	0.000088	0.000273	0.0012	0.00027	-
Total	-	-	0.0026	0.0065	0.0157	0.00200	-

Atomic Number Density

The atomic number density N is the number of atoms of a given type per unit volume of the material and is determined using the definition of Avogadro's number as follows:

$$N = \frac{N_A \rho}{A} \tag{5.5}$$

Where N_A is Avogadro's number (6.023 x 10^{23} atoms/mol), A is atomic weight or molar mass, and ρ is material density. For a chemical compound with a molecular weight of M, the atomic number density of the nuclei, as an i-th component, can be calculated as follows:

$$N_i = \frac{N_A \rho}{M} \gamma_i \tag{5.6}$$

where M is the molecular weight γ_i is the atom fraction of the i-th component in one molecule. The atomic number density can also be calculated using the weight fraction ω_i, where the relation between the atom fraction and the weight fraction is as follows $\omega_i = \gamma_i \frac{A_i}{M}$.

The Cross-section of Neutron Interaction

If there is one target nucleus in a unit area and one neutron passes through this area, the probability that a neutron will interact with the target nucleus is equal to the microscopic cross section of the interaction. It is denoted by σ and it is given in units of area (cm^2) or in reduced units of barn; 1 barn = 10^{-24} cm^2.

Depending on the type of interaction, we refer to:

- σ_a - absorption microscopic cross-section,
- σ_s - scattering microscopic cross-section,
- σ_t - total microscopic cross-section.

The total microscopic cross-section is equal to the sum of all effective cross-sections characterizing the interaction of neutrons with matter, and is therefore equal to:

$$\sigma_t = \sigma_s + \sigma_a \tag{5.7}$$

The Macroscopic Cross-Section

The macroscopic cross section is the product of the microscopic cross sections and the atomic number density of corresponding nuclei located in a unit volume. If there is only one type of nucleus, then for a given type of interaction, the macroscopic cross section is determined using the relationship:

$$\Sigma = N\sigma \tag{5.8}$$

The unit of macroscopic cross-section is cm^{-1} and can be interpreted as the average number of collisions that a neutron undergoes when travelling a distance of 1 cm. The inverse value of the macroscopic cross-section $1/\Sigma$ is equal to the mean free path of a neutron between two collisions λ.

The Dependence of the Absorption of a Microscopic Cross-Section on Energy

The value of the microscopic cross-section depends on the target nuclide, characterised by mass number and the energy of neutrons. An example of the energy-dependent fission cross-section $\sigma_f(E)$ for ${}^{235}_{92}U$ is shown in Figure 5.3. The cross-section significantly changes depending on the energy of the interacting neutrons. In accordance with the shape and energy, the cross-section can be divided into three regions.

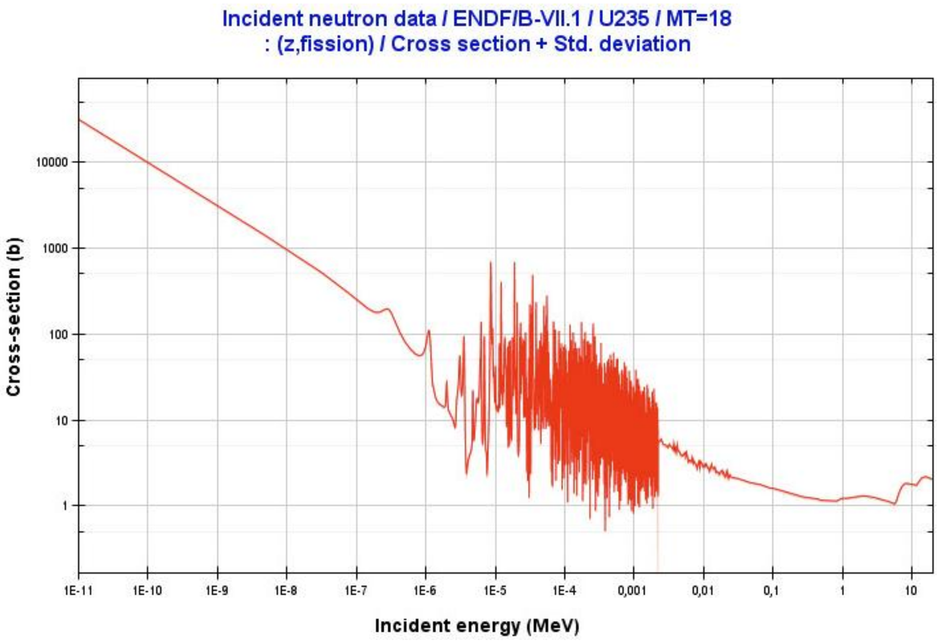


Figure 5.3 Energy-dependent microscopic cross-section of the absorption.

The first region, located in the energy range up to 1 eV, is called the thermal region. Here, the value of the microscopic effective absorption cross section gradually decreases with increasing energy. The change in the fission microscopic cross-section can be expressed by the relation:

$$\sigma_f(E) \approx \frac{a}{v} \tag{5.9}$$

Where a is a constant and v is the absolute value of the neutron velocity.

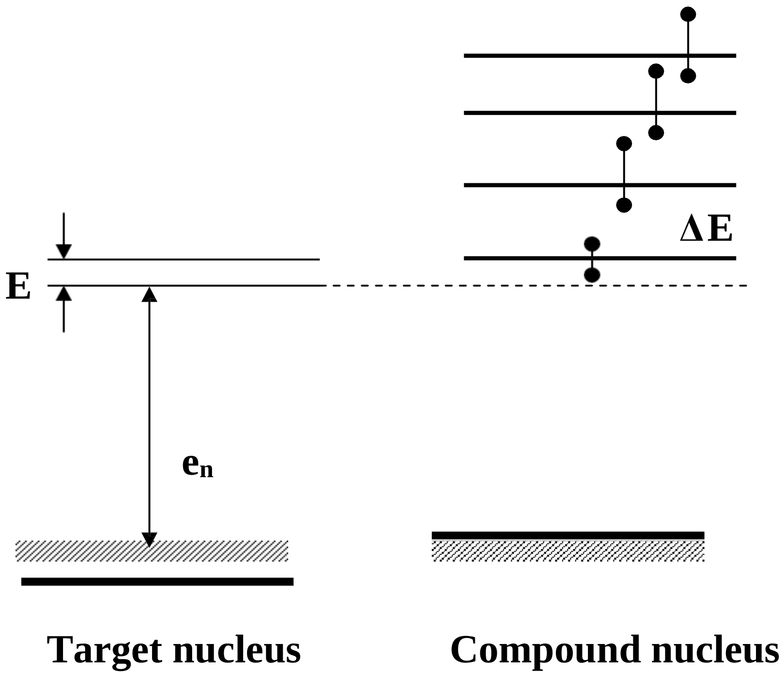


Figure 5.4: Energy levels of a compound nucleus.

The second region is characterised by significant changes in the value of the microscopic cross-section depending on energy. The shape is similar to resonance phenomena known, for example, in the theory of electrical circuits. Here, the value of the cross-section changes depending on whether, after neutron capture, a new nucleus is formed with energy quantum-mechanically determined, or whether the resulting energy of the nucleus acquires a different and therefore forbidden value. The energy of the new nucleus after neutron capture will be higher than the energy value of the target nucleus by the binding energy of the neutron in the new nucleus and the kinetic energy of the neutron. The average binding energy of a neutron in a heavy nucleus is ~ 7.5 MeV. The nucleus created by neutron capture will have an energy at least 7.5 MeV greater than the target nucleus. In this energy range, heavy nuclei have excited levels. The nucleus will remain at the excited level only for the shortest possible time, after which it will transfer part of its energy to its surroundings, for example, in the form of electromagnetic radiation. Based on *Heisenberg's* uncertainty principle $\Delta E \Delta t = \hbar$, it can be stated that each excited level has its own width. The relation also implies that as the excitation energy increases (the state is more natural, so Δt decreases), the width of the energy level also increases. In accordance with quantum mechanics, the distance between the centers of excited levels decreases as the energy increases. Therefore, above a certain energy, the excited levels overlap.

The energy of the composite nucleus changes depends on the kinetic energy of the neutron; therefore, it is in the energy range from 1 eV to 10 keV, significant maxima alternating with minimum values of the effective cross section can be observed. If a new nucleus is formed with energy corresponding to one of the excited levels after the neutron is captured by the target nucleus, this will be a state that is highly likely to occur, as expressed by the large value of the cross-section. If a new nucleus is to be formed with energy not corresponding to any of the excited levels after the neutron capture by the target nucleus, such an energy state is unlikely, which is reflected in a sharp decrease in the cross section to a low or zero value. This is evident from Figure 5.4. In the energy region above 10 keV, the resonant character of the cross-section disappears, as the excited levels overlap.

The third region of the cross-section energy dependence is characterised by a low and slightly changing value of the microscopic cross-section. This statement applies to all light and heavy nuclei, i.e., in this region there are no nuclei that strongly interact with neutrons. In terms of neutron energy, this part of the cross-section is called the fast neutron region.

Fission Chain Reaction

As was stated above, when the heavy element nuclei are split, more than two new neutrons are created for each split nucleus. This makes it possible to create, through a suitable combination of fissile material, moderator (used to slow down neutrons), coolant, structural material, and geometric configuration, a fission system in which a controlled fission chain reaction can be maintained. Every system containing fissile material is characterised by a parameter that reflects its neutron multiplying properties, therefore this parameter is called the multiplication coefficient and is denoted by k.

Thermal neutrons split ${}^{235}_{92}U$ nuclei, releasing energy and fast neutrons. The fission products transfer their kinetic energy to the environment, which results in the temperature increase. Fast neutrons enter the moderator, where they slow down and return to the fuel as thermal neutrons to contribute to further fission of ${}^{235}_{92}U$. Thus, the fuel elements serve as a source of heat and fast neutrons, and the moderator serves as a source of thermal neutrons. The fission chain reaction in the core is characterised by the parameter k_{eff} - the effective multiplication coefficient, which we will discuss in detail in the next section of this chapter. The value of k_{eff} can be influenced by changing the number of absorbers in the core, which is in the form of control rods or boride acid. By the change of position of the control rods or the change of boride acid concentration, the chain reaction of fission in the active zone is controlled. The material contained the fissile material is called nuclear fuel. For thermal reactors, uranium is mainly used as fissile material in various forms, such as metal, oxide, nitride, and carbide. Uranium in the form of pellets is encapsulated in materials that absorb neutrons very weakly and are sufficiently resistant to the effects of radiation damage and the chemical aggressivity of the coolant. In thermal reactors, alloys based on aluminium and magnesium, as well as zirconium and niobium alloys, are used. The coolant used in thermal reactors can be:

1. gaseous - carbon dioxide, helium, water vapour,
2. liquid - light water, heavy water, organic substances.

A moderator is a substance that effectively slows down neutrons. Moderators are usually:

1. solid - graphite, beryllium, beryllium oxide,
2. liquid - light water, heavy water.

Multiplication Coefficient

Let's discuss processes, which characterized multiplication properties of the system with fissile material and define the multiplication coefficient. At the beginning, consider a large medium, where the neutron leakage is negligible. The medium consists of a combination of a moderator and fissile material. Without preliminary investigation, assume that N_0 fast neutrons are available, and due to infinite dimensions, all these neutrons are absorbed within this media. Since the energy of these neutrons is higher than the fission threshold of uranium ${}^{238}_{92}U$, some of these neutrons will cause the fission of ${}^{238}_{92}U$ nuclei, thereby increasing the number of fast neutrons by a factor of ε. The ε is called the Fast fission factor and, by definition, represents the ratio of the total number of fast and thermal neutrons produced to the number produced by just thermal fission. Empirical relationships are usually used because it is a difficult parameter to calculate. If the fissile material is natural uranium, then ε =1.03, which is its maximum value. For pure ${}^{235}_{92}U$, $\varepsilon \approx 1$. Thus, after the absorption of N_0 fast neutrons in the fissile material, a total of $N_0\varepsilon$ new fast neutrons can start the process of slowing down. The energy of the neutrons is reduced as a result of their collisions with the moderator nuclei. During the slowing-down process, the energy of the neutrons decreases from $\bar{E}_0$ = 2 MeV (the average energy of prompt neutrons produced during fission) to E_T = 0.0253 eV, which is the energy of thermal motion of atoms in a given environment at a temperature of 20

°C. However, not all neutrons that have begun to slow down become thermal, because a certain portion of them are absorbed by ${}^{238}_{92}U$ nuclei in the resonance region (1 eV to 10 keV). Neutrons absorbed in this way cannot cause fission of ${}^{238}_{92}U$ nuclei because their energy is lower than the fission threshold of ${}^{238}_{92}U$ (4.1 MeV). For this reason, the absorption of neutrons by ${}^{238}_{92}U$ nuclei in the resonance region has a negative effect on the neutron balance. The loss of neutrons in the slowing-down process is characterized by the Resonance escape probability p that neutrons are not absorbed in the resonance region. The Resonance escape probability is given by the ratio of the number of neutrons that have reached the thermal region to the number of neutrons that have begun the slowing-down process. The Resonance escape probability is highest where the concentration of ${}^{238}_{92}U$ is zero, i.e., in pure ${}^{235}_{92}U$. As the concentration of ${}^{238}_{92}U$ increases, its value decreases.

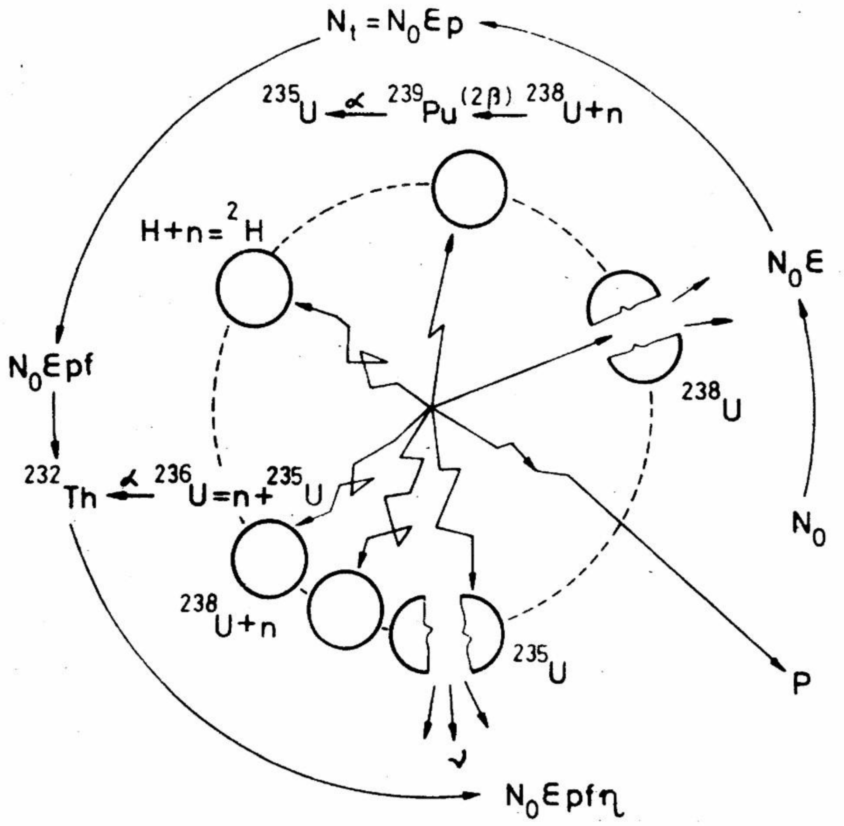


Figure 5.5: Neutron balance in the reactor core.

In this case, the slowing-down process began with $N_0\varepsilon$ fast neutrons, and only $N_0\varepsilon p$ neutrons reached the thermal region. Since the media is infinitely large, all neutrons that have become thermal are absorbed by the materials of the core. This means that some of the thermal neutrons are absorbed by the fissile material, some by the moderator, and the rest by the structural materials. In case of the multiplication properties, the fraction of the neutrons absorbed by the ${}^{235}_{92}U$ must be known. The proportion of neutrons absorbed by nuclei ${}^{235}_{92}U$ is expressed by the Neutron thermal utilization coefficient f or Fuel utilization factor. This coefficient is defined as the ratio of the number of thermal neutrons absorbed by nuclei ${}^{235}_{92}U$ to the total number of absorbed thermal neutrons. Then, from the total number of thermal neutrons $N_0\varepsilon p$, only $N_0\varepsilon pf$ neutrons are absorbed by nuclei ${}^{235}_{92}U$.

Not all neutrons absorbed by ${}^{235}_{92}U$ nuclei cause their fission, because some of these neutrons are radiatively captured, resulting in the formation of ${}^{236}_{92}U$, and the rest of the absorbed neutrons cause the fission of ${}^{235}_{92}U$. Therefore, the microscopic cross-section of absorption σ_a for ${}^{235}_{92}U$ is equal to the sum of the microscopic cross-sections of radiation capture σ_c and fission σ_f. The probability of fission in a single act of thermal neutron absorption by this nucleus is given by the ratio of the microscopic fission cross section σ_f to the microscopic absorption cross section σ_a.The probability of ${}^{235}_{92}U$ fission can also be expressed as the ratio of the corresponding macroscopic cross sections. As a result of the absorption of $N_0\varepsilon pf$ thermal neutrons, $N_0\varepsilon pf\frac{\Sigma_f}{\Sigma_a}$ fissions occur. In each act of ${}^{235}_{92}U$ fission, v_f of new fast neutrons with an average energy of 2 MeV are produced. If the number of fissions caused by thermal neutrons is multiplied by the average number of prompt neutrons produced in a single act of fission, the number of fast neutrons of the new generation $N_0\varepsilon pf\frac{\Sigma_f}{\Sigma_a}v_f$ is obtained. Product of fission probabilities and the average number of prompt neutrons per fission v_f is called the Neutron reproduction factor η. Thus:

$$\eta = \frac{\Sigma_f}{\Sigma_a}v_f \qquad (5.10)$$

The number of fast neutrons of the new generation expressed with the Neutron reproduction factor is written as follows:

$$N_0\varepsilon pf\eta \qquad (5.11)$$

The multiplication coefficient k is defined as the ratio of the number of neutrons in the n^{th} generation to the number of neutrons in the $(n-1)^{th}$ generation. In our case, there were N_0 fast neutrons in the $(n-1)^{th}$ generation and $N_0\varepsilon pf\,\eta$ fast neutrons in the n^{th} generation, so in our case, k will be given by:

$$k = \frac{N_0\varepsilon pf\eta}{N_0} \qquad (5.12)$$

After adjustment, the four-factor formula is obtained:

$$k_\infty = \varepsilon pf\eta \qquad (5.13)$$

Equation 5.12 expresses the multiplication coefficient in an infinitely large system, which is why the multiplication coefficient for an infinitely large system is denoted by k_∞.

Both slowing down and thermal neutrons can escape from a system of finite dimensions. The P_s is the probability that neutrons do not escape from a system of finite system during the slowing-down process and P_f the probability that neutrons will not escape from a finite system during the diffusion process. The product of both probabilities determines the probability that neutrons will not escape from the system, which is denoted by P, then:

$$P = P_s . P_f \tag{5.14}$$

The multiplication coefficient k_{eff} for a system of finite dimensions is then given by the relationship: $k_{eff} = k_\infty P$. The described process is schematically illustrated in Figure 5.5.

Reactivity and Its Units

In a fission system such as a nuclear reactor, neutrons produced during fission travel through the system, colliding with nuclei, which slow them down, absorb them, or cause them to escape from the system. Some of the captured neutrons cause new fission, resulting in the production of a new generation of neutrons. Neutrons produced in successive fission are characterised by the lifetime of one generation of neutrons, ℓ. In pressurised water reactors, the average lifetime of neutrons is $2x10^{-5}$ to $5x10^{-5}$ s, depending on the amount of fuel loaded. This means that in a nuclear reactor, between $1.4x10^4$ and $3.5x10^5$ generations of neutrons decay every second.

The system, in which the same number of neutrons is produced in each generation, is in the state called **critical**. Here the k_{eff} is equal the unity. But in some cases, the configuration of the fission system can change, then in each subsequent neutron generation, more neutrons are produced; this state is called **super-critical**, or less neutrons are produced than in the previous generation, and this state is called **sub-critical**. To quantify the level of sub- or super-criticality, the concept of reactivity was implemented. The reactivity of a fission system indicates the relative change of k_{eff} from one, i.e., from the critical state:

$$\rho = \frac{k_{eff} - 1}{k_{eff}} \tag{5.15}$$

In general, the reactivity of a fission system changes during operation as a result of changes in the content of fissionable material in the system, but also depending on changes in the physical properties of the environment caused, for example, by changes in temperature or configuration, etc.

The definition of reactivity implies that its value is dimensionless. It is a quantity expressed by values that differ very little from zero. In practice, reactivity is therefore often expressed in percentages, dollars, cents, pcm, etc. The purpose of these "units" is to increase the numerical value, which is more natural to use during reactor operation. Below are some frequently used units of reactivity.

Reactivity in dollars

In reactor technology, the reactivity unit **dollar** is often used, especially when measuring reactivity, for example, by the Rod drop method or by measuring with a reactimeter. Any reactivity can be expressed in dollars as the ratio of reactivity in absolute value to the effective delayed neutrons fraction, i.e., the following applies:

$$\rho(\$) = \frac{\rho}{\beta_{eff}} \tag{5.16}$$

Reactivity in cents

Reactivity in cents is determined as follows:

$$\rho(\cancel{c}) = \frac{\rho}{\beta_{eff}} 100 \tag{5.17}$$

Reactivity in percent

Reactivity in percent is determined as follows:

$$\rho(\%) = \rho 100 \tag{5.18}$$

Reactivity in pcm

Reactivity in pcm (percent milli rho) is expressed as follows:

$$\rho(pcm) = \rho 10^5 \tag{5.19}$$

CHAPTER 6: NUCLEAR REACTORS

The Classification of Nuclear Reactors

From an energy perspective, a nuclear reactor is a generator of heat that is released during a controlled, self-sustaining fission or thermonuclear **chain reaction**. In the narrower sense, a nuclear reactor is often understood to be a reactor operating on the principle of fission of heavy nuclei. A reactor that performs exothermic synthesis of light isotopes is often called a thermonuclear reactor.

Nuclear reactors can be classified according to many criteria (see Table 6.1). The most important of these is their use. Nuclear reactors can be used for educational purposes, for various research purposes, for the production of pure fissile materials (production reactors), for powering ships, submarines and rockets, for large-scale energy production at a given location (stationary energy reactors) and for various other special purposes (transport energy reactors for the production of smaller amounts of energy, reactors as sources of photon and neutron radiation for the production of radioisotopes or for the chemical production of substances with special properties). Stationary energy reactors produce heat that is either used directly (for industrial purposes, desalination of seawater, heating of large urban areas) or converted into electrical energy. Nuclear reactors are usually multi-purpose, and their operation serves several purposes at the same time. For example, the production of electrical energy and the production of new fissile materials.

An important criterion for classifying nuclear reactors is their ability to produce new nuclear fuel. If a nuclear reactor does not produce new fuel at all, but only burns pure fissile material, it is called a **burner** (e.g., PWR submarine reactors for highly enriched ^{235}U. If a nuclear reactor produces new fissile material, but of a different chemical type than it burns, it is called a **converter** or a **pseudobreeder**. Converters burn more fissile material nuclei than they produce as new ones (e.g., stationary PWR power reactors for mildly enriched ^{235}U produce ^{239}Pu). Pseudobreeders produce more new fissile material nuclei than they burn (e.g., Molten Salt) Breeder Reactors (see Table 6.2) for highly enriched ^{235}U and ^{232}Th burn ^{235}U and produce ^{235}U. Breeder reactors produce more nuclei of new fissile materials of the same chemical type than they burn (e.g., Liquid Metal Fast Breeder Reactors with ^{239}Pu and ^{238}U reactors burn ^{239}Pu and produce the ^{239}Pu).

Table 6.1: Classification of nuclear reactors.

Characteristics	Types
Purpose	Educational, research, production, transport, stationary energetic, special
Type of exothermic nuclear reaction utilised	Fission, thermonuclear
Fuel cycle	Burners, converters, pseudo-breeders, breeders
Neutron energy	Thermal, epithermal, fast
Core arrangement	Homogeneous, heterogeneous
Number of structural components of the core	Three-component, two-component, single-component
Fissile material	^{233}U,^{235}U,^{239}Pu, (^{241}Pu)
Fertile material	^{232}Th, ^{238}U, (^{240}Pu),
Chemical form of fissile or fertile material	Metal, oxide, carbide, (nitride, silicide), fluoride
Moderator	C, H_2O, D_2O, Be, (BeO), organic compounds, ZrH_2
Reflector	C, H_2 O, D_2O, Be, (BeO), organic compounds
Coolant	CO_2, N_2, He, NO_2,(dissociating gases), H_2O, D_2O, organic compounds, molten salts (LiF, BeF_2, ZrF_4), liquid metals (Na, K, Hg)
Reactor design	Pressure vessel, pressure (channels) pipes, pool-type configuration
Conceptual layout of cooling circuits	External with cooling loops, internal integrated in the reactor vessel

The most important physical characteristic of a nuclear reactor is the energy of neutrons causing fission. If this energy is greater than 1.6 x 10^{-14} J (0.1 MeV) (we recommend using eV for neutrons), the energy of the neutrons causing fission is approximately the same as the energy of fast neutrons from fission, which is referred to as **fast reactors**. If, on the other hand, this energy is less than 1.6 x 10^{-20} J (0.1 eV) and thus corresponds to the kinetic energy of the atoms in the environment with which the neutrons are in thermal equilibrium, these are **thermal** (slow) **reactors**. In some cases, neutrons with energies of 1.6x10^{-19} to 10^{-16}J 1 to 1,000 eV) or more are also used for fission. Such reactors are called **epithermal reactors**. In thermal and epithermal reactors, the neutrons produced in the fission process must be slowed down. The moderator, designed for this purpose, can be incorporated into a homogeneous mixture with nuclear fuel, or it can be spatially separated from the fuel in a heterogeneous grid. The design concept of the core determines the number of basic heterogeneous components. The three-component core comprises fuel, moderator, and coolant spatially and usually also separated by mass substance. Two-component cores are found in reactors without moderators (e.g., Liquid Metal Fast Breeder Reactors) or in thermal reactors in which the moderator and coolant are identical in terms of both substance and space (e.g., Pressurized Water Reactors). This group also includes reactors that operate with a fuel solution in the coolant (*e.g., Molten Salt Breeder Reactors)* or with fuel elements that form fissile material in a solid moderator (*e.g., High Temperature Gas-cooled Reactors).* Single-component cores are only possible in homogeneous reactors, where the fuel is dissolved or finely dispersed in the coolant, which also acts as a moderator in thermal reactors.

Table 6.2: International designation of nuclear power reactor types.

Designation	Meaning of designation	Moderator	Coolant
GCR	Gas-Cooled, graphite-moderated Reactor	Graphite	CO_2
AGR	Advanced Gas-cooled, graphite-moderated Reactor	Graphite	CO_2
HTGR	High-Temperature Gas-cooled, graphite-moderated Reactor	Graphite	He
LWGR	Light-Water-cooled, Graphite-moderated Reactor	Graphite	H_2O
BWGR (RBMK)	Boiling light-Water-cooled, Graphite-moderated Reactor	Graphite	H_2O
MSGR	Molten–Salt-cooled, Graphite–moderated Reactor	Graphite	Molten salts
MSBR	Molten-Salt-cooled, Graphite-moderated Breeder Reactor	Graphite	Molten salts
HWR	Heavy-Water-moderated Reactor	D_2O	Various
PHWR	Pressurised Heavy-Water-moderated and cooled Reactor	D_2O	D_2O
BHWR	Boiling Heavy-Water-moderated and cooled Reactor	D_2O	D_2O
HWGCR	Heavy-Water-moderated, Gas-Cooled Reactor	D_2O	CO_2
LWR	Light–Water–moderated and cooled reactor	H_2O	H_2O
PWR	Pressurised light–Water-moderated and cooled reactor	H_2O	H_2O
BWR	Boiling light-Water-moderated and cooled reactor	H_2O	H_2O
FBR	Fast Breeder Reactor	-	Various
LMFBR	Liquid–Metal–cooled Fast Breeder Reactor	-	Na
GFBR	Gas-cooled Fast Breeder Reactor	-	He
SFBR	Steam–cooled Fast Breeder Reactor	-	H_2O
OMR	Organic–Moderated and cooled Reactor	Organic	Organic

The basic physical concept of the core and thus the type of nuclear reactor determines the type of nuclear fuel used, its chemical form (which affects fuel density), moderator, and coolant. There are a relatively large number of options when choosing individual characteristics (Table 6.1) and an even greater number of combinations. However, not all combinations are physically possible (e.g., a homogeneous reactor with natural uranium or a heterogeneous reactor with natural uranium moderated by light water). Some combinations are structurally complicated to implement in a way that still meets basic physical requirements (e.g., a graphite gas-cooled reactor with natural uranium dioxide, a slow-neutron breeder implementing the uranium-plutonium fuel cycle, or a fast-neutron reactor cooled with light water).

Some physically possible combinations do not allow the desired technical objectives to be achieved (e.g., a fast pseudobreeder for enriched uranium or a light water steam-cooled fast breeder results in unacceptably long doubling times for fissile materials). Some combinations are clearly physically or technically inferior to others (e.g., heavy water-cooled graphite reactors or sodium-cooled light water reactors, etc.*)*. Therefore, the number of different designs of energy reactors implemented is not very large. To ensure efficient large-scale deployment of economic power reactors, it is essential not only to optimize the physical and technical viability of design combinations but also to focus development and manufacturing efforts on a limited number of standardized reactor types. Therefore, in global nuclear energy practice, which has so far focused on the uranium-plutonium fuel cycle, only the following combinations of moderators and coolants have remained in widespread use: graphite-gas (GCR, AGR, HTGR), graphite–light water (BWGR), light water–light water (PWR, BWR), heavy water–heavy water (PHWR), and sodium-cooled fast reactors (LMFBR). Gas-cooled fast reactors (GFBR) are considered promising. For the promising thorium-uranium fuel cycle, the following combinations of moderators and coolants are being considered: graphite – gas (HTCGR), graphite – molten salts (MSBR), and light water – light water (LWBR).

The Properties of Power Reactors

The most important properties of power reactors are those that determine the safety of their operation, the economics of energy production, and, where applicable, the economics of associated production of new fissile materials. These are primarily the most credible accidents, followed by unit power, specific volume power, coolant parameters at the reactor inlet and outlet, kinetic and dynamic properties of the reactor, and nuclear fuel reproduction intensity.

In addition to the design configuration, the properties of nuclear reactors are most influenced by the energy of fission neutrons, the type of moderator, the fission material, and the coolant.

The Unit Power of Power Reactors

From a technological standpoint, the unit power of an energy reactor represents its most intricate attribute. It reflects the level of technical maturity and operational mastery achieved for a given reactor type, signals its potential for further advancement, and plays a pivotal role in determining its economic viability.

The development of most commercial types of power reactors began between 1955 and 1960 (GCR, LWR, LWGR, FBR), with only HTGR and HWR reactors in the power version appearing about five years later, between 1960 and 1965. The speed of development also varies. For LWR and LWGR types, it took about 15 years to transition from a demonstration prototype to a serial unit with a thermal output of 3,000 MW. For GCR (continued in AGR), HWR, HTGR, and LMFBR reactors, this development is slower or has stopped.

The largest nuclear power plants (by capacity) worldwide as of August 2025 are shown in Figure 6.1

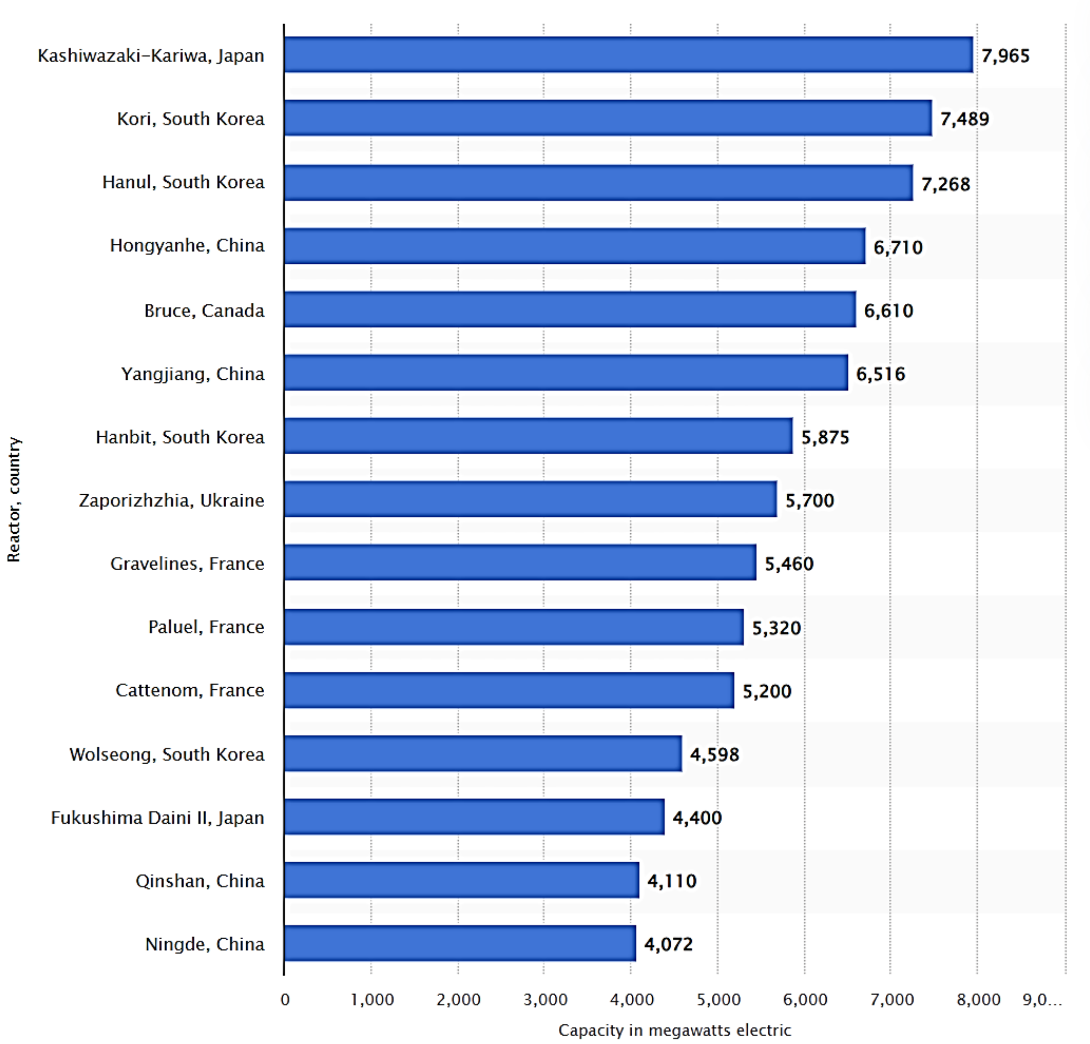


Figure 6.1 Ranking of leading nuclear power plants in megawatts electric (source: statista.com, 2025).

The Comparison of the Most Important Characteristics of the Basic Types of Power Reactors

Table 6.3 compares the most important characteristics of PWR, BWR, BWGR, HTGR, PHWR, and LMFBR power reactors at a power level corresponding to a net unit output of 1,000 MW_e. In cases where such units have not yet been deployed, their characteristics are extrapolated from the most advanced design features of existing lower-capacity reactors. Although the power characteristic of a nuclear reactor is its thermal output, electrical outputs are more commonly reported. These also include the impact of the overall efficiency of the nuclear power plant, which is influenced by other parameters of the nuclear unit.

Table 6.3: Comparison of the main characteristics of different types of power reactors with a net electrical output of 1,000 MW.

Characteristic	BWGR	PWR	BWR	HTGR	PHWR	LMFBR
Net electrical efficiency of the power plant [%]	30	33	34	41	31	43
Heat output [MW]	3,340	2,950	2,950	2,440	3,230	2,326
Fuel enrichment [%]	1.8	3.0	2.4	4.2	0.7	28
Fuel rod cladding material [-]	Zr-Nb	Zry-4	Zry-2	C-SiC	Zry-4	stainless steel
Max. fuel rod cladding temperature [°C]	-	380	380	800	320	650
Fuel rod diameter [mm]	13.5	10.7	12.5	12.7	15.2	5.8
Average fuel assembly diameter [mm]	80	242	155	380	90	150
Power density [kW/kg]	18	40	27	54	20	260
Active zone diameter [m]	9.6	3.1	4.5	6.7	4.7	2.7
Core height [m]	7.0	3.7	3.7	6.3	6.3	1.0
Number of core channels [-]	1,770	166	678	308	567	325
Mass of fuel [t]	188	74	129	45	160	8
Equivalent of natural U feed [t]	590	410	560	360	160	436
Thermal load of the core [kW/dm^3]	6.6	104	51	8.2	11	370
Burnup of equilibrium load [GJ/t$_{HM}$ (GWd/t$_{HM}$]	1,600 (18.5)	2,850 (33)	2,380 (27.5)	8,600 (100)	860 (100)	8,600 (100)
Equivalent burnup of natural uranium [GJ/t$_{HM}$ (GWd/t$_{HM}$]	51 (5.9)	520 (6.0)	540 (6.3)	1,080 (12.5)	860 (10)	160 (1.8)
Average conversion rate	0.6	0.5	0.6	0.6	0.8	1.2
Coolant	H_2O	H_2O	H_2O	He	D_2O	Liquid metal
Temperature at reactor outlet [°C]	284	326	284	760	300	562
Pressure at reactor outlet [MPa]	7.0	15.3	7.0	4.8	8.9	0.1

Temperature before the turbine [°C]	280	280	280	510	250	510
Pressure before the turbine [MPa]	6.8	6.8	6.8	17.0	4.1	17.0
Method of replacing fuel assemblies [-]	Continuous	campaign	campaign	Campaign continuous	Continuous	campaign

Light–Water–moderated and cooled reactor

The development of a nuclear reactor for submarine propulsion required compact and simple nuclear technology due to the large operating range and the impossibility of replacing fuel elements while at sea with extremely enriched fuel operating without conversion (burner reactors). The light water reactor (LWR) type PWR was chosen as the most suitable for this purpose. It was first tested on land (STR Mark I, Arco, United States, 1953) and later on the first nuclear submarine (Nautilus, United States, 1955). Developments around the world have confirmed the correctness of this choice.

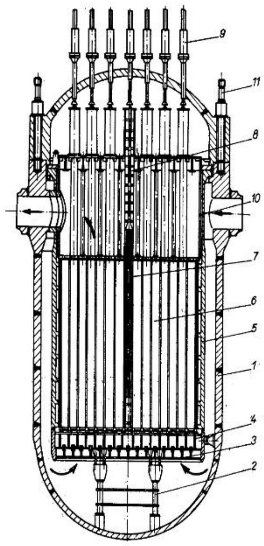
Today's PWR power reactors were developed as a stationary variant of the original transport and submarine reactors. Nuclear power thus gained reactors that were compact and sufficiently inexpensive, simple and highly reliable in operation, but which operate in a fuel cycle that is demanding on uranium raw material, which must be enriched in any case. The first demonstration nuclear power plant with a pressurised water reactor (Shippingport – 1, United States, 1957) confirmed the expected high economic potential of this reactor for the medium-term prospects of nuclear energy, paving the way for the extensive development of what is now the most widely used energy reactor.

Parallel to this development, light water reactors of the BWR boiling type were also developed, which were expected to further reduce the construction costs of nuclear power plants due to their single-circuit design. However, the first demonstration nuclear power plant with a boiling reactor (Dresden-1, United States, 1960) showed that this type did not have significant economic advantages, but that it was no worse than power plants with pressurised water reactors. Competitive reasons have led to both types of light water reactors being manufactured and supplied worldwide. In the USSR, demonstration nuclear power plants with pressurised water reactors (Novovoronezh-1, 1964) and boiling water reactors (Melekess, 1965) were put into operation. However, as the development of the BWGR (RBMK) channel-type boiling reactor continued in parallel, and it became clear that the economic potential of both PWR and BWR types was comparable, the decision was eventually made to develop only the PWR reactor.

Natural uranium cannot be used as fuel in light water reactors (the multiplication factor does not reach 1). The use of enriched fuel has removed the physical limits of the core in a narrower sense. The light water moderator with a short neutron migration length has compacted the fuel grid to such an extent that it has become technically impossible to place individual fuel channels outside the core pressure environment and thus enable continuous fuel replacement. Therefore, the campaign fuel exchange with poorer fuel economy was introduced. Light water cores have excellent self-regulating properties (large negative temperature and power reactivity coefficients) because, due to their compactness, the coolant serves as a moderator and thus follows all power changes in the coolant parameters. Increasing the power leads to under-moderation of the reactor. However, at certain times during the campaign, large excess reactivity (due to high burnup, high power reactivity coefficients) must be compensated for. The spatial compactness of these cores required very thorough neutron flux equalisation throughout their volume. The combination of all these requirements (compensation for large excess reactivity, balancing the neutron flux while maintaining a negative power coefficient of reactivity even in the early stages of the campaign) led to a very complex reactivity control and compensation system in light water reactors using absorption rods, burnout absorbers and varying degrees of fuel element enrichment (in BWR reactors, also by means of changes in coolant recirculation intensity).

Although light water reactors have a steel pressure vessel, they are not yet limited by this demanding structural component. Only in the former USSR, where there was a requirement for pressure vessels to be manufactured in a production plant and transported by rail, was the thermal output of the reactor limited to approximately 3,000 MW. In other cases, the power limit of light water reactors in terms of steel pressure vessels is approximately 6,000 MW. The actual technical limit of these reactors is the temperature of the fuel element cladding in terms of long-term mechanical properties and corrosion. The stainless-steel cladding used in the past did not limit the reactor temperature, while the zirconium cladding used today allows temperatures of almost 380°C to be reached. This determines the maximum temperature and pressure of the coolant, depending on whether boiling is to be prevented or, conversely, whether boiling is to be achieved. The second technical limit is the intensity of heat transfer from the fuel pin, which ensures that boiling does not occur under the given conditions, thereby preventing damage to the fuel pin cladding. For pressurised water reactors, this limit is close to 180 $W.cm^{-2}$, and for boiling reactors, 135 $W.cm^{-2}$.

The fuel elements of light water reactors have undergone significant development. Except for the fuel elements for parts of the core of the Shippingport-1 reactor, which had plate fuel elements, all fuel elements in light water reactors are longitudinal bundles of rod fuel elements. The number of fuel elements in a bundle is increasing (currently up to 289 in PWRs and 64 in BWRs), and their diameter is decreasing (currently approx. 10 mm in PWRs and 12.5 mm in BWRs) as the energy load of the fuel increases. All fuel elements are covered with a zirconium alloy (for PWRs this is usually zircalloy4, for BWRs zircalloy-2); only the first pressurised water reactors had austenitic stainless-steel cladding. The fuel elements of pressurised water reactors are channel-less tubes, so that the coolant is mixed in the core and balances its energy. In boiling reactors, the individual fuel elements are equipped with a square channel tube. The cores of light water reactors are inserted into a vertical cylinder. Depending on their power output, they have a diameter of 2.0 m to 3.7 m for PWR reactors and 3.3 m to 4.8 m for BWR reactors. Nowadays a typical fuel burnup is arround 40,000-60,000 MWd/t_{HM} for PWR reactors and 35,000-55,000 MWd/t_{HM} for BWR reactors. The conversion ratio varies widely between reactors, from 0.1 to 0.7, and is most often reported as around 0.5 for PWR reactors and around 0.6 for BWR reactors.



1. pressure vessel
2. damping supports
3. lower distribution plate
4. support plate
5. core barrel
6. fuel assembly
7. fuel assembly with bundle control rod
8. control rod drive
9. control rod hanger
10. upper support system
11. flange bolt

Figure 6.3: Pressurised water reactor (PWR) – Biblis nuclear power plant.

The mechanical control of both types of reactors is different. In PWR reactors, the absorption rods are controlled from above, so at a certain stage of development (Indian Point-2, United States), they could become part of the fuel elements and meet the requirement to distribute the absorbers as finely and evenly as possible in the active zone (bundled control rods). In BWR reactors, the control mechanisms are located at the bottom. This ensures more effective operation of the absorption rod in the lower part of the core, where the coolant has the lowest vapour phase content, and eliminates problems with cooling mechanisms that would otherwise operate in hot steam. Therefore, the absorption rods could not become part of the fuel elements (which are loaded from above); they had to retain their original form of cross rods and were controlled from below. The method of driving the control mechanisms is determined by their position. In PWR reactors, it is an electric or electromagnetic, and in BWR reactors, it is hydraulic.

The pressure vessels of light water reactors are gradually increasing in volume, from an original diameter of 2.7 m for PWR reactors and 3.7 m for BWR reactors to 5.0 m and 6.4 m, respectively. The height of the largest pressure vessels in PWR reactors is 13 m, and in BWR reactors, 22 m. In BWR reactors, the method of coolant recirculation is still being debated. To minimise the amount of highly radioactive coolant discharged from the reactor, water jet injectors (US method) or centrifugal pumps with drives located outside the pressure vessel (German method) are installed in the reactors. In Europe, there is also a concept of removing the entire recirculating flow from the reactor.

The change of coolant parameters at the reactor outlet is very slow in light water reactors. In PWR reactors, the temperature of the primary water rose from 280 °C and 7.13 MPa. The net thermal efficiency increased from 26% in PWR reactors and 29% in BWR reactors, and today it reaches 33% and 34% for both types, respectively. The highest net unit electrical output for both types is approximately 1,700 MW.

CHAPTER 7: NUCLEAR FUEL CYCLE

Nuclear fuel is the active, neutron-fissile material that forms the basic component of a nuclear reactor. The active materials of fuel rods (elements, cells) are divided into two groups according to their purpose:

- fissile materials (provide a fission reaction),
- breeding materials (ensuring the creation of new nuclear fuel).

Fissile materials of nuclear fuels are divided into:

- primary fissile materials (naturally occurring, e.g., uranium isotope ^{235}U),
- secondary fissile materials (not found in nature at all or only in ultra-trace amounts and obtained artificially by neutron irradiation in a reactor, e.g., ^{233}U, ^{239}Pu, ^{241}Pu).

The breeding materials include ^{232}Th and ^{238}U:

$$
\begin{aligned}
&^{232}Th\ (n,\gamma)\ ^{233}Th \xrightarrow{-\beta} {}^{233}Pa \xrightarrow{-\beta} {}^{233}U \\
&^{238}U\ (n,\gamma)\ ^{239}U \xrightarrow{-\beta} {}^{239}Np \xrightarrow{-\beta} {}^{239}Pu
\end{aligned}
\tag{7.1}
$$

The basic fissile materials are **natural uranium** (which has the following isotopic composition: ^{238}U=99.274%, ^{235}U=0.720%, ^{234}U=0.006%) and **enriched uranium** (also used in VVER-440 nuclear power reactors. In Slovakia, profiled nuclear fuel with varying enrichment levels in individual rods (3.3%, 3.6%, and 4% of U-235) is or was used, with an average enrichment of 3.82% in the fuel assemblies. Nowadays, fuel assemblies with burn-up absorbers and an average enrichment of 4.87 % are also used.

Uranium

Uranium is the most important material for nuclear power. It has an atomic number of Z=92 and is alpha-radioactive. Its most important isotopes are:

- ^{238}U (half-life $T_{1/2} = 4.5\times10^9$ years),
- ^{235}U ($T_{1/2} = 7.1\times10^8$ years),
- ^{234}U ($T_{1/2} = 2.5\times10^5$ years)
- ^{233}U ($T_{1/2} = 1.6\times10^5$ years) - prepared artificially by irradiating thorium ^{232}Th with neutrons in a nuclear reactor.

Uranium is tough, silvery metal, relatively soft, and can be forged or rolled at room temperatures. The melting point is 1133 °C. It occurs in three crystalline modifications: alpha phase (up to 660

°C, orthorhombic lattice, ρ=19.08 $g.cm^{-3}$), beta phase (from 660 to 760 °C, tetragonal lattice, ρ=18.11 $g.cm^{-3}$), gamma phase (from 760 to 1133 °C, cubic spatially centred lattice, density ρ=18.00 $g.cm^{-3}$). In air, uranium oxidizes rapidly at elevated temperatures. It is therefore mainly processed in a vacuum or inert atmosphere. By annealing in air, it burns to triuranium octoxide (U_3O_8). It corrodes more rapidly in contact with water or water vapour than in air. The radiation resistance of uranium can be increased by alloying (Cr, Ce, Y, Be, Mo, Fe, Zr, AL, Si) with optimum heat treatment.

Uranium Stockpiles

In the Earth's crust, uranium is present in concentrations of 2 to 4 g/t. Higher concentrations occur in some geological formations, which, once explored and accessed, may become a resource and economically recoverable reserves. The volume of exploration work in recent years has been in line with the expected trend in nuclear power development and is now, like mining, experiencing some stagnation due to the saturation of the market with uranium. Until 1980, the volume of the world's identified geological uranium reserves was growing steadily at an average rate of 20,000 tonnes of uranium per year. After 1980, there was a significant reduction in the scale of exploration work. This resulted in a stagnation in the growth of proven reserves. Uranium ore reserves are classified according to the degree of verification and the cost of mining and processing, usually in US$/lb U_3O_8. (lb = pound, 1 lb = 0,4536 kg, 1 lb U_3O_8 = 0.38466 kgU, 1 kg of uranium = 2.5997 lb U_3O_8). Verified and, similarly, inferred reserves are further subdivided into groups up to 80 and 80 -130 USD/kgU, respectively. According to the OECD NEA 2022, the total proven reserves in the world in the price category up to 260 USD/kgU amount to around 7.918 million tonnes of U. In 2006, the Uranium Institute in London reported (using its classification) that proven reserves with a price of up to USD 40/kgU were around 1.32 million tonnes of U, which at the current world demand of 84,000 tonnes of natural uranium per year alone would be enough for just over several tens of years. The future increase in nuclear capacity can be seen more specifically in the WNA's 2003 and 2005 forecasts, which show projections of capacity development up to 2030. The forecast is shown in Figure 7.1.

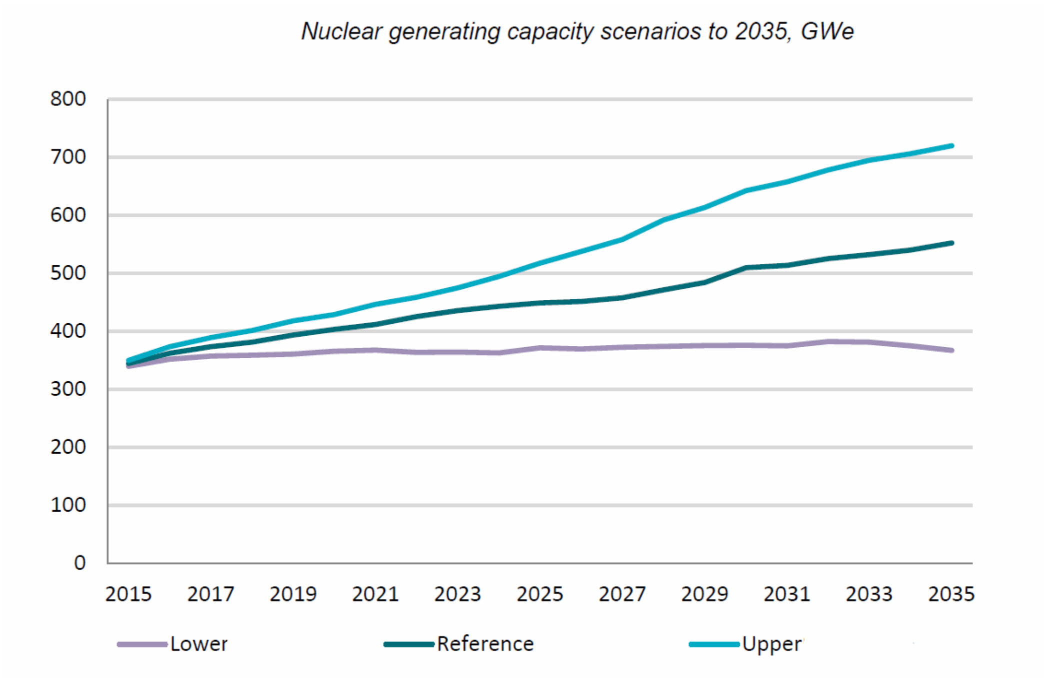


Figure 7.1: World Nuclear Capacity Forecast to 2035 by WNA 2005.

The exploration for new uranium sites and the exploitation of uranium deposits are taking place at ever greater depths, which has resulted in rising exploration and consequently extraction costs. As of 2024, uranium's finding costs make up only 2% of the recent spot price of 30 USD/lb (78 USD/kg_U), while the oil finding costs are 12% of a recent spot price of 50 USD/bbl.

Uranium deposits were first discovered in the world in Bohemia, in the Jáchymov region, in the uranium mineral known as pitchblende (uraninite). A little later, uranium was also found in Africa and the northwestern part of Canada. Today, Australia (37 % of the world's proven reserves) and Canada (18 %) are the world's main producers of uranium. These countries have high metallicity ores. Russia, Kazachstan and some other countries of the former Commonwealth of Independent States, in turn, have the largest leachable reserves (21 % in total). In Africa (10 %), there are large deposits in South Africa, Gabon, and Niger. The rest of the reserves are divided among 16 other countries. Currently, the uranium content of mined ores (sandstones, quartz-sandy conglomerates, uranium veins and chambers, pegmatites, granites, schists, etc.) ranges from 0.02 % to 2-3 % U (sometimes more). Uranium can also be obtained as a by-product of gold and copper mining and phosphoric acid production. Very low-grade or unconventional sources such as black shales, monazites, coal, and seawater also contain large amounts of uranium.

Uranium Mining

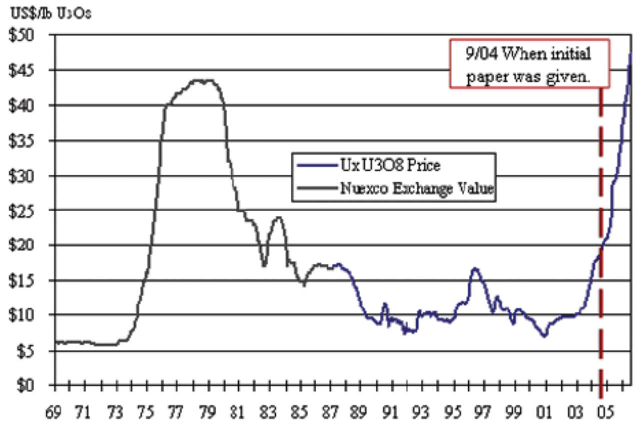
About 80 % of uranium ore is mined underground; the rest is extracted by open-pit mining. Under certain conditions, uranium can be extracted by in situ leaching. The mining method used is generally chosen based on the characteristics of the ore deposit in terms of extraction, such as the size of the deposit, the quality of the ore, the depth, and the condition of the bedrock. Underground mines are at depths from 30 to more than 1000 m, and open pit mines can be as deep as 150 m. In 1996, 35,350 tonnes of natural uranium were produced worldwide (taken from Nukem 1996), but the need was about 64,070 tonnes (figure from Uranium Institute 1996). Just for the sake of comparison, it should be noted that already in 1981, about 40,000 tonnes of uranium were produced in the world (excluding the Eastern Bloc countries), with uranium concentrate extracted from about **80 million tonnes of** ore. In 2024, the world's need for reactors is still around 80,000 tonnes of U per year but is expected to grow slowly.

Uranium Price

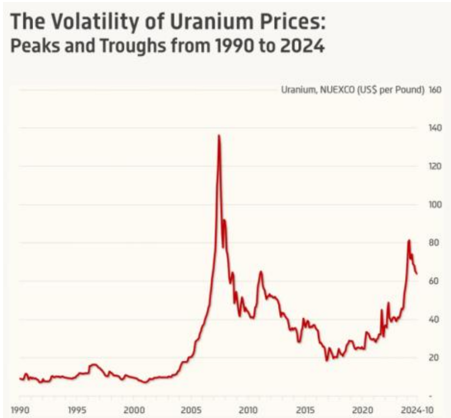
In the 1960s and 1970s, programmes were proposed to build large power reactors, which required rising uranium production. This was particularly evident after the 1973 oil crisis. The price of uranium rose and reached a peak of US$ 43/lb U_3O_8 in 1979 (see Figure 7.2a). Subsequently, uranium producers reacted faster than the need for nuclear power, and overproduction resulted. Huge uranium stockpiles were built up, which caused a reversal of price trends. Investment and operating costs were greatly increased by mining at greater depths, inflation, and environmental costs that had been virtually unforeseen before. The reduced metallicity of the ores mined also had some impact on concentrate production, which has remained virtually flat, although ore volumes have increased significantly (e.g., almost doubling in the US). This and the significant fall in the price of uranium on the open market in the 1980s meant that virtually only supplies tied to long-term contracts were secured. To cover long-term contracts with nuclear power plants, US fuel producers preferred to buy uranium on the open market (where prices were lower) rather than to mine it domestically. The production capacity of mines in operation or idled in the US was about 24 040 t_U/year, of which 10,000 t_U/year was idled, and the rest was only 50 % operational.

In 1990-94, the CIS countries (mainly Russia) entered the Western markets with their low prices and partly threatened the relatively expensive production in the USA. Subsequently, similar practices - anti-dumping regulations - were introduced by the US administration, but also by Euratom. For the first time, free market prices were divided into higher (capped) for the US and lower (uncapped) for non-US markets. At the same time, Russia and the US agreed to the dismantlement of nuclear warheads and the subsequent commercial use of fissile material. Under the 1993 intergovernmental agreement, Russia is to export 500 tonnes of reprocessed enriched uranium, derived from dismantled nuclear weapons to the US by 2013. The program was successfully completed in December 2013, resulting in the elimination of HEU equivalent to approximately 20,000 nuclear warheads. The resulting LEU was used to generate about 10% of the electricity produced in the United States during the program's duration.

Fuel prices are now becoming something of an unknown for the projected development of nuclear power. In the recent past, when nuclear power was almost marginal, the market for natural crude nuclear fuel behaved abnormally. Since 1979 (~\$100/kg U_3O_8), prices have continuously declined and reached a low in 2001 (~\$15/kg U_3O_8). Production capacity in the world has not been expanded or renewed. Since then, however, prices have risen steadily. Between January and July 2007 alone, uranium prices on the open market rose by almost 100% to ~\$300/kg U_3O_8. Subsequently, from August 2007 onwards, prices started to decline with some fluctuations (Figure 7.2b) and currently (March. 26, 2024) reach values of around \$65/lb U_3O_8.



a) 1969 - 2006, (1 lb = 0.4536 kg)



b) Uranium prices 1990 - 2024, the y-axis is the price in USD/lb U_3O_8

Figure 7.2: Uranium prices.

However, the overall prices for complete nuclear fuel are much higher than those for "raw" uranium and depend on many factors. Enrichment services, the actual final production of the tablets and fuel assemblies, including demanding control operations (up to 30% of the total price), are the largest contributors to the price. Currently, the price of a fuel assembly for pressurised water reactors ranges from \$3000 to \$8000 per kilogram of uranium, depending on the enrichment of the uranium.

Uranium Ore Processing

Includes technological procedures for obtaining ore and chemical concentrate. The mined ore is ground in ball or autogenous (aerofall) mills to particle sizes below 0.15 -0,30 mm. The resulting dust particles are collected in hydrocyclones, and the slurry passes through a concentration line where about 40 % of the rock is separated. The ore concentrate is further processed by chemical leaching of the sand slurry with H_2SO_4 (acid leaching) or by alkaline leaching. Leaching is followed by the separation of the liquid component from the solid ore residues and their re-washing with water. Uranium is separated from the leach by sorption on ion-exchangers or liquid amine extraction is used. After saturation of the ionex or organic phase, the uranium is re-extracted with various chemical reagents ($NaNO_3$, Na_2CO_3, H_2SO_4, etc.). From the solutions obtained, a **chemical concentrate** (powdered ammonium diuranate) with a uranium content at least 60-65 % is precipitated, which is also called **yellow cake** because of its colour. Most uranium ores processed today contain approximately 0.02 to 0.2 % recoverable uranium, and therefore, 0.5 to 5 tonnes of uranium ore must be processed to obtain 1 kg U.

Chemical concentrate is the feedstock for nuclear fuels. The most used fuel is natural or slightly enriched U, usually in the form of high-purity uranium dioxide (UO_2). **Refining and conversion processes** are necessary to produce high-purity uranium and to convert uranium compounds from a crude yellowcake composition to a composition suitable for direct fuel cell production or enrichment. These processes produce a nuclear pure uranium hexafluoride UF_6 from the chemical concentrate. For UF_6 production wet or dry refining and conversion methods can be used.

In the **wet route,** the chemical concentrate is first dissolved in nitric acid (HNO_3), the resulting solution is filtered, and then the uranium is extracted with tributyl phosphate (basic purification operation). The product of the re-extraction is a solution of nuclear pure uranyl filtrate, which, after isolation, is converted by heating to uranium oxide (UO_3) and further thermal decomposition to triuranium octoxide (U_3O_8). The latter is reduced by hydrogen or cracked ammonia to uranium dioxide (UO_2), from which uranium fluoride - UF_4 - is obtained by hydro fluorination (from which uranium metal can be obtained by reduction of Mg or Ca). Subsequent fluorination with fluorine gas produces UF_6.

In newly constructed plants, cleaning and conversion are carried out in a **dry route**. The delivered concentrate is first heat-treated, and the uranium contained in the concentrate is converted to U_3O_8. This is reduced by hydrogen or cracked ammonia to UO_2, hydrofluorinated, and finally fluorinated. Subsequent vacuum rectification produces UF_6 of the required quality for the enrichment process. The dry process is cheaper and has the advantage that purification is the final operation, so the product cannot be contaminated with impurities. In reprocessing plants, the recycled uranium is converted into UF_6 and re-enriched for further use in reactor fuel. The process is similar, with the addition of a decontamination stage to separate the radioactive burn-up products, and the size of the individual plants is limited by the criticality of the system due to the possible higher contents of ^{235}U and ^{239}Pu.

Uranium Enrichment

Many isotope separation techniques have been developed for uranium enrichment. All separation methods are based on the different physical or physicochemical properties of the isotopes and their compounds and are usually derived from the different masses of their atoms. For most elements, the relative change in mass of individual isotopes is quite small, which makes the separation process difficult. The efficiency of different separation methods can be characterized by **the separation coefficient (factor) α**, which can be expressed as the ratio of the relative abundance of the separated isotope after and before separation. If α differs only slightly from unity, the separation process must be repeated many times. The oldest and currently most used is **diffusion technology**. It uses the different velocities of UF_6 molecules for different isotopes of uranium as they pass through a porous semi-permeable membrane with apertures ranging from a few units to tens of nm for isotope separation. Such a device consists of vessels divided into two parts by porous baffles. A gas (e.g., in the case of uranium, UF_6) is introduced under low pressure (~0.1 Pa) from one side of the vessel, and a vacuum is maintained in the other part of the vessel. Following the principle of uniform energy distribution, which follows from the kinetic theory of gases, a slightly larger proportion of lighter molecules (at the same energy, they have a greater velocity) will penetrate the semipermeable layer than heavier molecules. The ratio of the concentrations behind and in front of the baffle, irrespective of time, is called the separation coefficient and depends on the ratio of the masses of the UF_6 molecule made up of the heavier and lighter isotopes of uranium. For uranium with 3% enrichment, it is necessary to include 1,000 to 1,500 separation steps in the cascades. The **centrifugal approach** is based on the separating effect of a strong centrifugal field in a rotating cylinder (centrifuge), suitably combined with the cascade effect of counter-current circulation on the UF_6 isotope mixture. In a centrifuge with very high inversion speeds (circumferential velocity reaching 400 to 700 m/s), heavier molecules are concentrated at the circumference and lighter ones in the central part near the axis. Although the separation factor of a single-stage centrifugation process is 1.1 to 1.5 (depending on the rotor length and the circumferential speed of the cylinder), cascades should be used in this case as well. For uranium with 3 % enrichment, a minimum of 12 separation stages are required.

Aerodynamic processes for the separation of uranium isotopes are based on the dependence of centrifugal force on the mass of molecules in a rapidly heated gas stream. Separation nozzles have been developed in which a mixture of H_2 and UF_6 gases (about 5% UF_6) flows through a set of curved slits. The achieved separation factor is between the values of the centrifugal and diffusion processes. **Laser procedures** separate isotopes in uranium atomic pairs or a molecular compound. The **photoionisation method** of atomic laser separation is preferred, where a tuneable laser excites individual ^{235}U atoms to form ions, which are then separated electromagnetically from the isotopic mixture. The input material is uranium metal, which is converted into atomic vapour in an electron furnace**.** The **photodissociation method** uses gaseous UF_6 as the input medium, and molecules containing ^{235}U are selectively separated by laser and separated again, e.g., by filtration. **Chemical processes** use different chemical properties in exchange reactions between two chemical substances in different phases; **plasma processes** are based on the different ion cyclotron resonance of uranium isotopes. **Enrichment plant capacity** is expressed in **separative work units (SWU)**, which is a quantitative measure of the degree of separation and the amount of enriched material produced. It is the effort that helps to overcome the difficulties in all the different stages of the enrichment cascade (in both the enrichment and depletion parts) and that must be expended to progressively enrich the product to the desired concentration or, conversely, to deplete the raw material to the desired residue. The magnitude of the separative effort required (SWU) depends on the quantity of uranium processed and the degree of isotopic enrichment needed. Enrichment plant capacities are typically expressed in separative work units per year (SWU/year), while the specific separative work required per kilogram of enriched uranium produced (SWU/kg enriched U) depends on the enrichment levels of feed, product, and tails. The separative workflow has the same dimension as the nuclear material flow, i.e., the unit used is 1 kgU/year.

Another operation in the production of nuclear fuel is the so-called **reconversion**, which is the conversion of enriched UF_6 to UO_2. There are three different UF_6 reconversion processes used industrially. The **ADU procedure** is named after the ammonium diuranate intermediate. First, UF_6

is hydrolysed with water, and then ADU is precipitated from the solution with ammonia. The precipitate is washed with ammonia water, purified from F, and decomposed to U_3O_8 (500 °C) by annealing. It is then reduced with hydrogen at temperatures between 500 and 800 °C to UO_2. The disadvantages of this process are the high number of operations and the difficult filtration of the ADU.

The **AUC procedure** is used in most Western countries. The name is again derived from the intermediate, the crystalline precipitate of ammonium uranyl carbonate (AUC). AUC is decomposed and reduced in the presence of hydrogen at 500 to 600 °C to UO_2. Reduction of the fluorine content is accomplished by pyrohydrolysis with water vapour at 650 °C. After this treatment, powdered UO_2 is chemically passivated by mild oxidation to a stoichiometric ratio of about $UO_{2,1}$.

The **IDR approach** (Integrated Dry Route) is used in the UK. The process is a dry route, i.e., UF_6 is hydrolysed by water vapour to solid uranyl fluoride (UO_2F_2), which is then reduced to UO_2. In the above processes, there is some uranium loss, which cannot be reduced practically.

The literature states that, for an annual fresh fuel loading (equilibrium loading) of a VVER-440 reactor with an average enrichment of 3.6 % ^{235}U, the following uranium masses are required at various stages of the fuel cycle - from uranium mining to finished fuel rods - assuming a ^{235}U concentration of 0.25 % in the depleted enrichment tails:

- equilibrium loading — 14,000 kg enriched U
- entry into the production of fuel rods — 14,140 kg enriched U
- reconversion input — 14,170 kg enriched U
- enrichment input — 98,390 kg natural U
- conversion input — 98,880 kg natural U
- input of chemical concentrate production — 99,080 kg natural U
- mined ore contains — 107,000 kg natural U
- The number of units of separative work required — 100,000 SWU

In addition to the enriched product, the production of enriched uranium for the fuel of light-water reactors produces **depleted uranium**_with a concentration of ^{235}U in the range of 0,20 to 0,30 weight percent (wt. %). For example, the production of fuel for VVER-440 with 3,5 % enrichment (for equilibrium loading equalled to 14,000 kg) produces 84,220 kg of depleted uranium with a concentration of ^{235}U of about 0.25 wt. %. Depleted uranium in the form of UF_6 gas is usually stored directly at the enrichment plants in cylindrical steel containers in the open air. It represents a certain strategic reserve which would allow further use of part of the remaining ^{235}U. It is estimated that residual ^{235}U concentrations as low as 0.05 wt.% can be achieved by laser enrichment.

Plutonium

Plutonium has atomic number Z=94 and many isotopes, all of which are alpha-radioactive. The oldest isotope ^{244}Pu has a half-life of $T_{1/2}$ = 373,000 years. The most important and predominant isotope is ^{239}Pu with $T_{1/2}$ = 24,360 years. It is found in ultrapure quantities in uranium ores. Since its abundance in uranium is of the order of only 10^{-12} wt.%, it is formed mainly in nuclear reactors specially designed for this purpose. They utilise the reaction:

$$^{238}\text{U}\ (\text{n},\gamma)\ ^{239}\text{U} \xrightarrow{\beta}\ ^{239}\text{Np} \xrightarrow{\beta}\ ^{239}\text{Pu}. \qquad (7.2)$$

Other isotopes such as ^{240}Pu, ^{241}Pu, and ^{242}Pu are also produced by long-term neutron irradiation. Metallic plutonium is obtained by the reduction of plutonium fluoride PuF_3 with barium vapour. Density equals ρ = 19.74 g.cm^{-3}. Plutonium occurs in 6 allotropic modifications (transition $\alpha-\beta$ as early as 120 ^{o}C). The melting temperature is 640 ^{o}C. During solid-state phase transformations, the material experiences significant volume changes, leading to large internal stresses that may cause the castings to crack or rupture. Because of these properties, but also due to its unfavourable physical properties (brittleness, low thermal conductivity), pure plutonium metal is not suitable for the production of fuel cells (alloys with uranium, thorium, molybdenum, zirconium, and PuO_2 oxide are usable). Chemically, plutonium is very active. It is dark grey, oxidises rapidly in moist air, but is almost unoxidised in dry air, and is therefore its best protective atmosphere. It is highly toxic, much more so than other nuclear materials. The critical mass of Pu is considerably less than that of uranium (^{235}U). The minimum critical mass in a $Pu(SO_4)_2$ solution with a reflector is only 0.257 kg, and therefore, plutonium must be processed in small amounts. Plutonium is a very suitable fissile material for fast reactors (the larger average number of neutrons released during fission increases the fuel reproduction coefficient). However, it is important in the form of mixed MOX fuel (i.e., UO_2/PuO_2) not only in fast reactors but also as a fissile material already in thermal reactors. Nowadays, MOX fuel is increasingly deployed in light water reactors in Western countries for technical and economic reasons.

CHAPTER 8: PROSPECTIVE REACTORS

Nuclear energy has been undergoing a period of rapid innovation as researchers and industry seek reactor systems that are safer, efficient, and sustainable. Equal emphasis is placed on the economic competitiveness of emerging technologies. Generation IV International Forum (GIF) defined generation IV nuclear reactor technology as a set of the most advanced concepts currently under development. These reactor systems aim to address limitations of earlier designs by improving inherent and passive safety, minimizing waste generation, enabling fuel-cycle sustainability, and opening new applications such as industrial process heat or hydrogen production. While still in various stages of research, demonstration, and early commercialization, GEN IV technologies illustrate the future trajectory of nuclear engineering and the global energy landscape. Information included in this chapter is sourced mainly from the GIF (GEN IV International Forum n.d.).

The Classification of GEN IV Technologies

The current reactor technologies are largely based on proven materials, mechanisms, and design features. Thanks to the use of conventional technologies, there is a great understanding of the NPPs' behaviour, increasing the effectiveness of safety culture in the nuclear industry. However, modern material science and advancements in fabrication and construction present possibilities of reactor systems with improved parameters. Beyond the basic improvements, such as efficiency, safety, etc., decarbonization efforts present new possible use cases for the new technology. The most notable feature which gained traction due to the new commercial requirements is the production of high-temperature heat, directly usable in industrial processes such as metallurgy, hydrogen production, CO_2 capture, etc.

The terms of GEN IV technologies encompass all design choices, and the GEN IV technologies could be categorized based on several aspects:

- Neutron spectrum: thermal spectrum, fast spectrum.
- Coolant: supercritical water, molten salts, liquid metal, gas.
- Fuel form: liquid, pebble bed, rods, plates, etc.
- Fuel composition: molten salts, oxides, metal alloys, carbon matrices, etc.
- Fuel cycle: open, closed.

Besides these aspects, the GEN IV technologies also include innovative construction materials and components outside the reactor vessel. The last aspect, which is largely connected to the GEN IV technology, is the miniaturization and modularization of both existing and new reactor technologies into the form of small modular reactors (SMRs). The GEN IV reactor concepts usually combine several of these innovations.

The GIF identified six potential GEN IV reactor technologies (GEN IV International Forum n.d.): **molten salt reactors** (MSRs), **supercritical water-cooled reactors** (SCWRs), **very high-temperature reactors** (VHTRs), **gas-cooled fast reactors** (GFRs), and two liquid-metal-cooled fast reactors (LMFRs), the **lead-cooled fast reactor** (LFRs) and the **sodium-cooled fast reactors** (SFRs). The main aspects of these reactor technologies are listed below in Table 8.1. All the mentioned concepts have both promising capabilities and several hurdles that need to be overcome. For example, the MSR and LMFR concepts feature highly corrosive coolants but allow the creation of highly efficient breeder/breeder-and-burner reactor designs. It must be noted that most of these reactor technologies have been proven in the past, either fully or partially. However, the obstacle presented by these technologies is not the proof-of-concept, but rather proof-of-safety, economic viability, sustainability, etc.

Table 8.1: Overview of main aspects of GIF-recognized GEN IV reactor technologies (GEN IV International Forum n.d.).

GEN IV technology	Neutron spectrum	Outlet Temperature °C	Fuel cycle
VHTR (Very-high-temperature reactor)	Thermal	900-1000	Open
SCWR (Supercritical-water-cooled reactor)	Thermal/fast	510-625	Open/closed
MSR (Molten salt reactor)	Thermal/fast	700-800	Closed
GFR (Gas-cooled fast reactor)	Fast	850	Closed
SFR (Sodium-cooled fast reactor)	Fast	500-550	Closed
LFR (Lead-cooled fast reactor)	Fast	480-570	Closed

All designs which utilise a fast neutron spectrum have one feature which is very desirable. Due to the reduced neutron absorption compared to the moderated systems, fast systems can operate as a breeder or breeder and burner reactors. These capabilities might significantly improve the nuclear fuel economy and nuclear waste management, allowing the disposal of weapon-grade plutonium and actinoids in spent fuel. The use of fast spectrum, however, means that the initial fissile inventory must be substantially larger than for thermal spectrum systems due to the decreased fission probability. Using the SFR enrichment figures as an example, the EBR-I and EBR-II initial average uranium enrichment achieved 90 % (Zinn 2024) and 67 % (Feldman, et al. 1987) respectively. The Phénix reactor, which utilised mixed oxide fuel (MOX), contained between 20 % to 25 % of plutonium enriched to around 77 % of ^{239}Pu.

In addition to the six main categories, GIF also recognizes additional sub-categories of small modular reactors (SMRs). SMR technology has a primary goal of decreasing the initial burden of commissioning new NPPs, as well as improving the financial sustainability of maintaining and scaling the reactor fleet. As such, SMR technology does not necessarily depend on any specific technological improvement. Rather, the industry-wide adoption of SMRs relies on fundamental economic principles to decrease the cost per unit of installed power.

Very-High-Temperature Reactors

The Very High Temperature Reactor (VHTR) builds on the operating history of gas-cooled reactors used in several countries and employs TRISO fuel, a helium coolant, and a low power density that enables passive removal of decay heat. Although early VHTR concepts aimed for extremely high outlet temperatures to support hydrogen production, newer studies and market analyses indicate that more moderate temperatures, around 700 to 850 °C, can meet industrial needs while reducing technical hurdles. As a result, the focus has moved from higher outlet temperature designs, such as in DRAGON (UK) and THTR (Germany) reactors, to lower outlet temperature designs, such as HTR-PM (China). The expectation, however, is that improvements in technology and operational experience will pave the way for higher output temperature (above 1000 °C) in the future.

Designed for combined heat and power generation, the reactor's high-temperature output is well-suited for applications in hydrogen systems and in sectors such as chemicals, oil refining, and iron production. In addition to process heat capability, the VHTR offers benefits such as inherent safety characteristics, strong thermal efficiency, comparatively low operating costs, and a modular construction approach. The utilisation of helium gas is advantageous, since it is chemically inert, non-corrosive, and transparent.

The most interesting feature of VHTR technology is the fuel, which is built from tiny TRISO particles, each less than a millimetre across. At the centre is a fuel kernel, which is encased in multiple layers of carbon and silicon carbide that securely retain fission products even at temperatures above 1600 °C. These particles can be configured in two main ways: they may be pressed into cylindrical compacts that fit into graphite blocks shaped like hexagonal prisms, forming what is known as a prismatic-block core, or they can be embedded within graphite and silicon carbide shells to form spherical pebbles roughly 60 mm in diameter, used in pebble-bed reactor designs.

The commercial viability of VHTR technology requires solving a few key technological challenges:

- Achieving fuel resistant to temperatures up to 1800 °C under accident conditions.
- Achieving fuel capable of burnup up to 200 GWd/t_{HM}.
- Preventing power peaking and large temperature gradients in the core.
- Limiting structural degradation from air or water ingress.

Currently, only two facilities are in operation, the High-Temperature Engineering Test Reactor (Japan) and HTR-PM (China), and only a few projects are currently under development compared to other technologies, such as SFR. Both prismatic-block core and pebble-bed VHTR designs utilise the same layout, with a primary loop connecting the gas coolant from the core to the heat exchanger and a secondary loop, also with gas coolant, connecting from the heat exchanger to the turbines or cogeneration unit.

Supercritical-Water-Cooled Reactors

Drawing on decades of operating experience with conventional water-cooled reactors, as well as long-term industrial use of supercritical fluids in fossil-fired power plants, Supercritical-water-cooled reactors (SCWRs) are based on well-established technologies. Supercritical (SC) systems have been common in the energy sector for many decades, with the first supercritical boiler introduced in 1960, largely because they offer improved thermodynamic efficiency and therefore require less fuel for the same power output.

SCWRs operate above the critical point of water (approximately 374 °C and 22.1 MPa) and can be configured to use thermal, fast, or mixed neutron spectra depending on the core design. Two major design lines exist: one adopts a large pressure vessel similar to PWRs and BWRs, and the other uses pressure tubes and a calandria vessel, as in CANDU reactors. It is important to emphasize that the SCWRs are still considered water-cooled reactors, possibly simplifying the licensing process. However, successful design must overcome some nontrivial technological challenges:

- Manufacturing of advanced materials capable of sustaining structural integrity under SC conditions, without negative impact on neutron economy.
- Development of suitable testing procedures, simulating SC conditions, allowing research of SC and near SC thermohydraulic systems.
- Development and validation of suitable computational tools.
- Demonstration of proposed passive safety systems.

One of the key advantages of using supercritical water is its single-phase behaviour, which enables simpler plant layouts. Many SCWR concepts, therefore, use a direct power cycle, eliminating the need for steam generators and associated equipment. This simplification can reduce initial capital costs and boost reliability. With these design features, SCWRs aim for thermal efficiencies on the order of 44–48% or higher, compared with roughly 34–36% for today's water-cooled reactors.

Historically, SCWR technology had seen only limited demonstrations. Important experience was obtained from the operation of units such as the Beloyarsk pressure -tube boiling water reactors (Russia), which operated above the critical temperature (at 500 °C) but deep below the critical pressure (at only 8 MPa). Many SCWR designs are currently under development, such as Super LWR and Super FR (Japan), CSR1000 (China), VVER-SCP-600 (Russia), or ECC-SMART (EU, Canada, China). However, no SCWRs are currently under construction or in operation.

Molten salt reactors

The Molten salt reactor (MSR) technology is a technology with the highest amount of variability between the design approaches and desired parameters. The fundamental idea behind MSRs is the use of molten salts, such as salts based on fluorine, chlorine, lithium, etc., as a coolant medium. However, many different parameters can vary:

- Fuel form: fuel can be in the form of either a conventional/unconventional solid state, or liquid, dissolved in the coolant itself.
- Neutron spectra: proposed designs consider either thermal, epithermal, or fast neutron spectra.
- Fuel cycle: closed fuel cycle relying on either uranium, thorium, or depleted fuel from other reactor designs.

The most interesting concept, considering the safety, fuel cycle efficiency, fuel recycling, and actinoid burning, is the molten salt fuel reactor. These designs can theoretically improve the fuel cycle significantly by dissolving the fuel (fissile and fertile material, actinoids, etc.) in the fluoride salt coolant. These designs propose continuously regulating the fuel-coolant mixture composition, achieving continuous refuelling, higher burnup with a high breeding rate, a flexible fuel cycle, and lower waste volume.

The most promising feature of MSR technology also represents the biggest obstacle to achieving safe and reliable design. Use of molten salts at high temperatures leads to a high level of thermomechanical and corrosive strain on all components in contact with the coolant. Furthermore, dissolution of fuel in the coolant means that the composition of the coolant will change drastically with growing depletion. Therefore, the characteristics of the coolant, such as melting and boiling temperatures, might also change substantially. Consequently, the chemistry control of the coolant must be highly efficient and reliable to ensure stability of the system. The challenges can be summarized as follows:

- Material development.
- Monitoring of the chemical composition of molten salts.
- Online purification of molten salts.

An important milestone in the past of MSR technology is the MSRE (USA), which was operated in the 1960s and demonstrated the possibility of the technology. Currently, several projects are in various stages of development or construction. Amongst projects such as the FLiBe burner MSR (Russia), CAWB and CMSR (Denmark), the Wuvei prototype (China) is the most notable, as the first MSR since MSRE to produce electricity.

Gas-Cooled Fast Reactors

The Gas-cooled fast reactor (GFR) technology shares many similarities with the VHTR. The goal is again to increase the outlet coolant temperature, improve thermal efficiency, and possibly supply high-quality heat to industrial applications. Similarly, to the VHTR, most GFR designs utilise helium gas. Compared to the VHTR, however, the omission of the moderator potentially allows closing of the fuel cycle. However, the fast neutron spectrum also increases the strain radiation damage rate and requires increased power density, removing the potential safety advantages of VHTR technology.

The referential design is based on a 2400 MWth core with helium outlet temperatures around 825 °C at a pressure of 7 MPa. Due to these extreme thermomechanical conditions, the referential design utilises ceramic-clad, mixed-carbide-fuel pins contained within a ceramic hex-tube. The favoured ceramic material today is silicon-carbide fiber-reinforced silicon carbide ceramic. The design's success is quite dependent on improvements in material and component manufacturing. The main challenges can be summarized in 4 requirements on components:

- High thermomechanical resistance.
- High tensile fatigue and long-term creep resistance.
- Corrosion, oxidation and embrittlement resistance.
- Improved manufacturability and joining techniques.

The GEN IV GFR technology is based on extensive experience with gas-cooled graphite moderated reactors and VHTR. Although historically gas-cooled systems such as Magnox (UK) and UNGG (France) utilised a moderated neutron spectrum and carbon dioxide gas, new designs with fast spectra benefit greatly from the materials and air-tight construction techniques developed during their operation. According to the GIF, no GFR reactor has ever achieved a criticality, even though several projects such as GBR (EU), GDFR (USSR), or GBM (Germany) were in operation in the past. Currently, there are 4 significant projects developing GFR technology: helium coolant-based ALLEGRO (EU), EM2 (USA), and HeFASTo (EU), and one project based on supercritical carbon dioxide coolant – KAMADO FBR (Japan). Typically, the GFR designs utilise either a double or single-loop configuration.

Sodium-Cooled Fast Reactors

Despite ongoing challenges in its development, the Sodium-cooled fast reactors (SFRs) draw on the collective experience of over 20 reactors globally, amounting to more than 400 reactor-years of operation. This extensive experience has progressively improved the safety and reliability of these reactors. Among Generation IV systems, the SFR boasts the highest number of constructed reactors and the most comprehensive operational history. In fact, the first ever "SFR" was the Experimental Breeder Reactor I (EBR-I), which utilised sodium-potassium coolant and a non-moderated spectrum. The first power production occurred at 20^{th} of December 1951, proving the concept of fuel breeding as well as the use of liquid metal coolant. Notable examples of SFRs under construction are the commercial Russian BN-1200 and the Chinese demonstration unit CFR-600. Several other projects focused on the development and conceptual designs include the Natrium (USA), HEXANA (FR), ESFR-SIMPLE (EU), etc.

The use of sodium presents 4 main challenges:

- Sodium induced corrosion, ablation, and deterioration of components.
- Sodium fires.
- Sodium-induced explosions.
- Sodium opacity.

Although the possibility of sodium fires and explosions due to the leaks is a considerable risk, the experience with the BN-600 has shown manageability. In 38 years of operation between 1980 and 2018, 27 sodium leaks were detected, and 14 sodium fires were put out. Most of the leaks occurred at the beginning of the operation, and despite the initial complications, the BN-600 life expectancy was extended to 60 years.

Most SFR designs feature the pool-type configuration where the primary loop and primary-to-secondary heat exchanger are integrated into the reactor vessel. The separation of the in-core and sodium loop limits the potential impact of sodium explosion. Furthermore, the retention of sodium inside the reactor vessel is advantageous also due to the large thermal capacity of sodium compared to water, improving the characteristics in case of LOFA in the primary loop, etc.

Lead-Cooled Fast Reactors

The main goal of the Lead-cooled fast reactor (LFR) technology is effective actinoid transmutation with electricity production. The main feature of LFR designs is liquid lead or lead-bismuth coolant with a very low level of neutron moderation. Thanks to the very high boiling point of the coolant (1743°C), these systems can operate at atmospheric pressure with high temperature. Furthermore, favourable neutronic and radiation shielding properties allow proposals of relatively small designs. The use of lead/lead-bismuth coolant compared to sodium is also advantageous, since the lead-based coolant does not react with air or water. Like other fast reactors, LFRs utilize MOX fuel, combining Uranium and Plutonium, which enables the closing of the fuel cycle and the burning of transuranic actinides. This enhances fuel efficiency and reduces the volume and activity of radioactive waste. Current R&D collaborations focus on addressing LFR's material, chemical control, and fuel cycle challenges.

LFR technology has 4 main challenges to overcome:

- High lead melting temperature: Preventing the solidification of coolant in the primary loop will require maintaining temperatures above 327 °C.
- Lead opacity: Together with the melting temperature, the low opacity requires new techniques for inspection, repair, and monitoring of in-core components.
- High density of lead: Structural design requires more careful consideration to manage seismic impacts.
- Lead-induced corrosion: Conventional materials used in reactor systems must be replaced or protected from excessively interacting with the coolant.

Currently, there are no LFRs in operation worldwide (apart from submarines). According to GIF, the only LFR under construction is the Russian BREST-OD-300, which started in 2021. The goal of this reactor is the demonstration of the LFR technology and onsite closure of the fuel cycle. Should the project be successful, the BREST-OD-300 will serve as the design base for BR-1200. Several designs are under development, most notably the ALFRED and ELFR (EU), MYRRHA (Belgium), LFR-AS-30 and LFR-AS-200 (Newcleo Italy/UK/France).

Small modular reactors

From the point of view of fundamental reactor technology, the push for SMR designs does not imply a need for a substantial leap in the philosophy of design of different NPP components. For example, both NuScale-designed NPP, the VOYGR (NuScale Power 2012) and Westinghouse-designed AP300 (Westinghouse Electric Company May 2023) are constructed around small-sized pressurized water reactor (PWR), utilizing only conventional technologies for heat and electricity generation. The AP300 is presented as a direct downscale of a proven AP1000 NPP with 6 reactors in operation, 6 reactors under construction, and 19 reactors in different stages of pre-construction planning (Westinghouse Electric 2025).

The unconventionality of miniaturized designs stems from inherent advantages of smaller components: an increase in production volumes, the possibility of modularization and standardization, passive safety features, etc. For example, leveraging the small size of the two KLT-40 S reactor units (Baybakov, et al. 2016), the floating nuclear power plant (FNPP) Akademik Lomonosov, provides a portable electricity source, which can be deployed in remote locations or after natural disasters. One less conventional SMR design is the Chinese high-temperature gas-cooled reactor (HTGR) with pebble-bed fuel module – HTR-PM. The NPP began commercial operation in late 2023 (Zhang, et al. 2024), becoming the first pebble-bed HTGR utilizing modular design, and a second commercial NPP utilizing SMR technology after the commissioning of Akademik Lomonosov in 2019. The combination of SMR and HTR-PM technology provides increased resilience to loss-of-coolant accidents (LOCAs) (Zhang, et al. 2024) even in case of damage beyond baseline design, such as the primary loop pipes rupture (Zheng and Shi 2010).

Application of different GEN IV reactor concepts on the SMR technology can present further economic, safety, and ecological advantages. For example, some designs are inherently suitable for use in desalination plants – LWR, HWR, PWR (Yoo, et al. 2025), and other designs are more fit for cogeneration mode. The high operational temperature of SCWR, GFR, MSR, and LMFR designs allows for hydrogen production, process heat production, and desalination on top of electricity production (IAEA 2024). Both electricity production and other capabilities beyond electricity production can have wide applications in different industries, and miniaturization of the designs into SMR units could stimulate investment from the private sector. Several private companies, such as Amazon, Google, or OpenAI, expressed a large interest in the integration of SMR units into their data centers (Small Modular Nuclear Reactors Suitability for Data Centers 2024).

The very basic classification scheme of different SMR types provided by the International Atomic Energy Agency (IAEA) is depicted in Figure 8.1. A complete overview of SMR projects is provided by IAEA Advanced Reactors Information System (ARIS) in Ref. (IAEA Advanced Reactors Information System (ARIS) 2020).

Conventional NPPs vary in scale, with typical thermal power output of one reactor core unit ranging from around 1000 MW_{th} in the case of VVER-440, up to 3900 MW_{th} in case of advanced boiling water reactors (ABWRs). Conventionally, different components of NPPs must be constructed on-site, since the large dimensions do not allow for prefabrication and transport of, for example, pressure vessels, heat exchangers, turbines, etc. Such projects are known as monolithic NPP designs, and this design philosophy has different economic advantages and disadvantages.

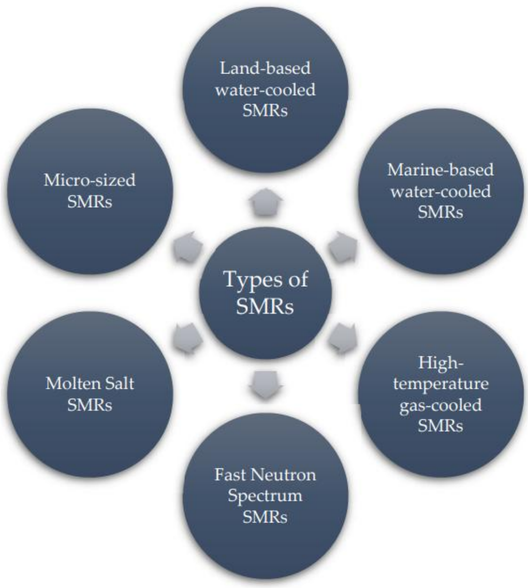


Figure 8.1: Basic SMR classification recognised by IAEA (Vinoya, et al. 2023).

The Economy of nuclear power plants

Throughout its history, apart from efficiency and safety improvements, the nuclear energy industry gravitated towards increasing the scale of individual reactor and power plant designs. The reason behind the increasing sizes of the power plants in general is the economy of scale principle. The life-cycle costs are generally divided into four groups:

- Capital cost: Includes all initial expenditures like land, licensing, contracting, administration, etc. (WNA 2023), and the interest during construction (IDC) (MIT 2018).
- Operational and Maintenance cost: All non-fuel costs required for safe NPP operation.
- Fuel cost: Includes all costs in the specific fuel supply chain, ranging from uranium ore mining or purchase of fuel to the final fuel waste disposal (NEA 2020).
- Decommissioning cost: Includes all activities related to remediation of the original site and disposing of any radioactive waste (IAEA 2013).

The capital cost represents between 50 to 75% of the whole life cycle cost of NPP (Mignacca and Locatelli 2020). Increasing the NPP scale improves the cost efficiency - power to cost ratio, due to so-called vertical economy of scale principle. The increase in size or number of components leads to advantageous disproportional gain in output, compared to overall costs. For one reactor NPP design, the capital cost CC scaling with power output PO is described as:

$$CC_2 = CC_1 \left(\frac{PO_2}{PO_1}\right)^n \tag{8.1}$$

where n is a factor of scalability, characteristic of the NPP design *(Aydogan, et al. 2015, Maronati and Bojan 2018)* from interval (0, 1). The capital cost to power output equation can be transformed into a form of cost efficiency or capital cost per unit of power output CpP:

$$\frac{CC_i}{PO_i} = CpP_i \tag{8.2}$$

to obtain more comprehensive equations comparing cost efficiency gain ε_{cost} to power output gain $\varepsilon_{power}^{n-1}$ the following equation can be used*:*

$$\frac{CpP_2}{CpP_1} = \left(\frac{PO_2}{PO_1}\right)^{n-1} \tag{8.3}$$

$$\varepsilon_{cost} = \varepsilon_{power}^{n-1} \tag{8.4}$$

The PWR designs from the VVER family can be used to obtain a very rough estimate of the capital cost per power unit for a theoretical NPP based on theoretical miniaturized VVER-440 (VVER-77) with the power output of the NuScale SMR design NPP, the VOYGR (NuScale Power 2012). Considering the VVER-440 capital costs per power unit (NEA 2016) as a baseline, efficiency and power output gains can be calculated for VVER-640, VVER-1000 and VVER-1500, using inflation adjusted data from Ref. (Poullikkas 2013). The factor of scalability for similar PWR designs can be obtained by fitting using Eq. 8.4 as can be seen in Figure 8.2

The reduction of capital cost per power unit when scaling up the design is only a rough estimate, and more in-depth analysis cites around 20% to 35% capital cost per power unit reduction (Mignacca and Locatelli 2020) when doubling the power capacity. However, the estimated scalability curve suggests that downscaling the VVER-440 to 77 kW_e theoretical VVER-77 would lead to an increase of cost per unit of power output by a factor of approximately 3.5. However, this very simplified model for cost scaling does not take into account several nuances, since studies conducted on this topic reference a maximum increase of 70% (Carelli, et al. May 11-15, 2008, Playbell 2017, Boarin, et al. 2011). The main problem with the approach of upscaling monolithic NPPs is the increased initial investment and long commissioning time, as well as unexpected delays. This is exaggerated by the IDC (MIT 2018). Furthermore, since such mega-projects are scarce, the retention of a highly skilled workforce and know-how in the industry is problematic. The exercise provided is based on the inaccurate assumption of “other things being equal”, meaning that the number of projects and demand will not change. It is also important to note that the theoretical design of VVER-77 considered a classical approach to constructing a monolithic NPP, while the VOYGR is based on a modular construction philosophy. However, the smaller power output of small reactors would lead to an increase in the number of projects, volume of components, etc.

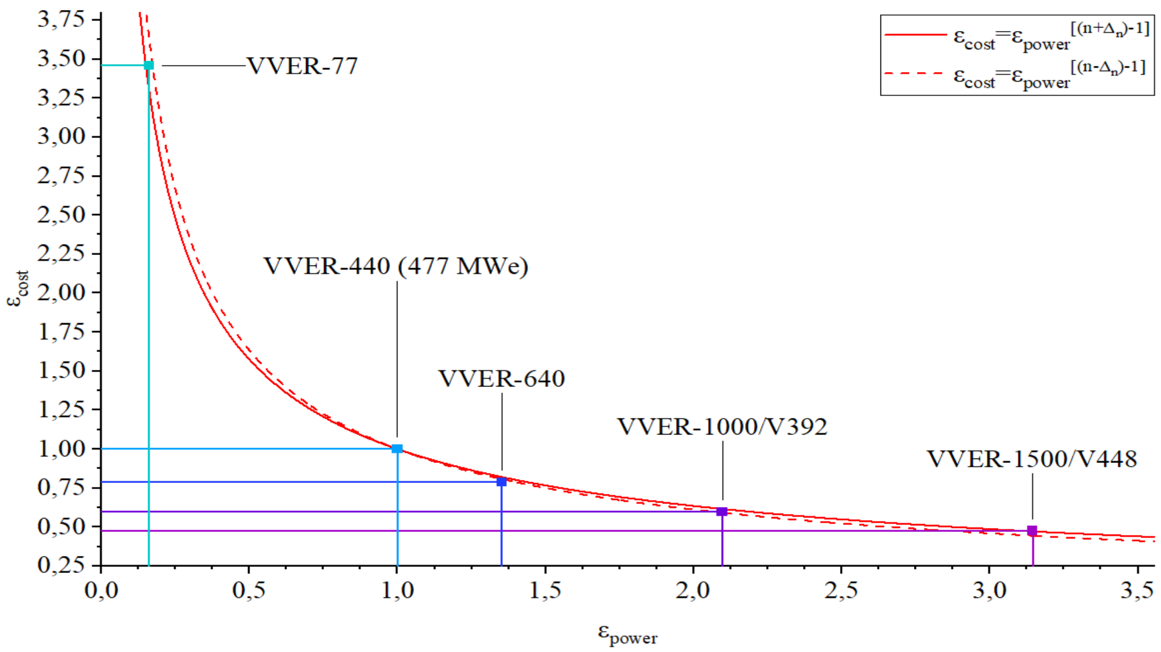


Figure 8.2: Capital cost per unit of power for 4 different VVER designs, and a purely theoretical small core VVER-77 design.

Due to the high level of modularity and increase in demand, the SMR technology could improve cost efficiency thanks to horizontal economy of scale, also known as scale of multiplicity. Several aspects need to be considered:

1. Factory fabrication: Improved quality and reliability of components. Although factory fabrication could lower labour costs per module, the initial setup will require substantial investments.
2. Standardisation: Increased module production volume and simplified in situ installation. Reduced construction error rate and commissioning time, decreasing both capital and IDC costs. Possible sharing of skilled personnel and spare parts.
3. Level of modularisation: Studies shown that 60% of modularisation was considered the minimum to justify the SMR design. Modularisation of about 66% could potentially decreased expected construction time of 60 months down to 42-48 months (Loyd and Roulstone 2018) .
4. Co-Siting: To achieve power output comparable to conventional NPPs, a larger number of SMRs could be constructed at one site, reducing capital cost (and decommissioning cost) per SMR thanks to sharing of basic supporting infrastructure such as power grid connection, road, and sewage infrastructure.
5. Incremental capacity implementation: In case of both co-siting and decentralised NPPs, the final output can be potentially met by commissioning reactor units in sequence, using revenue from commissioned units to fund the commissioning of subsequent units, limiting the capital at risk and need for loans.
6. Cogeneration: Lower capital cost for SMR could incentivise the use of reactor units as a source of process heat for various industries, such as metallurgy, petrochemical industry, residential heating, etc.

The modularity of SMRs can combine both the positive aspects of vertical and horizontal economies of scale. While the economy of modules such as pressure vessels, steam generators, etc. would be scaled vertically, with large production volume, the modules themselves can be combined, scaling the economy of power plants vertically. Instead of the lengthy and costly commissioning of one conventional-sized reactor, the powerplant site can comprise of multiple reactors with matching or lower combined power output with possible future expansion. This approach, however, still presents several obstacles, namely the initial cost efficiency, licencing and expansions of the laws and regulations.

CHAPTER 9: THE FUNDAMENTALS OF RADIATION PROTECTION

In Slovakia, radiation protection is defined by the **act No. 87/2018** Collection of Laws of the Slovak Republic, which is in accordance with the European directive, the Council Directive 2013/59/Euratom, from 5 December 2013, which lays down basic safety standards for protection against the dangers arising from exposure to ionizing radiation. Ionizing radiation is radiation in the form of particles or electromagnetic waves, which is able to create ions, directly or indirectly. The electromagnetic waves are considered to be ionizing in the case their wavelength is 100 nm or lower, or their frequency is 3×10^{15} Hz or higher.

The radiation safety directives do not refer to: irradiation caused by usual cosmic rays, by radionuclides naturally occurring in the ground, by radionuclides naturally occurring in the human body (C-14, K-40), by natural mineral water, irradiation of passengers in planes or space shifts, or visitors to caves, or irradiation of patients during medical treatment. The directives refer to any work with ionizing radiation or to radionuclides occurring in the ground processed by a human.

Sources of Ionizing Radiation

The sources of ionizing radiation are:

- Radioactive materials.
- Devices containing or releasing radioactive materials.
- Generators of ionizing radiation (X-ray tubes, accelerators).

The radioactive material is material whose activity is not negligible from the point of view of radiation safety. The particular activities for each nuclide are directly given in the act attachment (No. 87/2018). A typical solid alpha source with a diameter of 2 cm is shown in Figure 9.1.

Figure 9.1: Solid alpha source typically used in laboratories with a diameter of 2 cm.

Basic Principles of Radiation Protection

Three basic principles of radiation protection are:

1. Any work leading to exposure to radiation of a person must have a reason and its benefits must overcome possible health problems.
2. The irradiation must be As Low As Reasonably Achievable - ALARA
3. The irradiation of a person must not exceed the given limits.
4. The Principle of Justification of Practices Involving Exposure.

A practice that leads to radiation exposure may be carried out only if it is justified, meaning that the potential detriment it may cause is outweighed by the expected benefits to individuals or to society. Any decision that alters an existing exposure situation must result in a net benefit.

All new practices involving exposure must be justified before being introduced. The justification of existing practices must be re-evaluated whenever significant new knowledge is acquired regarding their effects or associated risks. For major radiation sources (e.g., nuclear power plants), the justification is decided by the government or the competent national authority, typically including public consultation involving operators, expert bodies, and the general public.

The Principle of the Optimization of Radiation Protection (ALARA)

Optimization requires that the probability of exposure, the number of exposed individuals, and their individual doses be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.

Optimization applies to all exposure situations:

- in **planned** exposure situations: **dose and risk constraints** are used,
- in **existing** and **emergency** exposure situations: **reference levels** are defined.

Optimization methods may be qualitative or quantitative. Detailed procedures and technical requirements are specified in Annexes to Act No. 87/2018 Coll.

Qualitative optimization includes:

1. evaluation of the exposure levels of individuals,
2. application of dose limits or reference levels,
3. consideration of technical, organizational, and economic factors,
4. use of established examples of good practice.

Quantitative optimization compares:

- the costs of protection measures (changing the radiation source, relocating personnel, shielding, PPE) with
- the monetary value of the expected benefit resulting from dose reduction.

A level of radiation protection is considered **reasonably achievable** if further measures would result in higher costs than benefits or would require disproportionate societal impact.

An indicative value used in optimization for workers is **20 mSv per year**, considering the entire planned lifetime of the technology.

Optimization does not need to be demonstrated when:

1. no worker receives an annual effective dose exceeding **1 mSv**, and no other individual exceeds **10 µSv**,
2. the implemented protection meets the applicable standards for the specific practice or source.

The Principle of Dose Limitation

Exposure from all **controlled sources** in planned exposure situations must not exceed established dose limits. The only exception is **medical exposure of patients**, where dose limitation does not apply.

Any person performing activities involving ionizing radiation must ensure that doses received by workers and members of the public do not exceed legally defined limits.

Exposure categories:

- occupational exposure – workers.
- public exposure – members of the public.
- medical exposure – patients.

Dose limits are further categorized for:

- the public,
- occupationally exposed workers,
- students and trainees.

Dose limits do not apply to:

- medical exposure of patients,
- individuals caring for or comforting patients treated with radionuclides,
- volunteers participating in biomedical or medical research.

Dose Limits in Slovakia in a calendar year

Occupational Exposure:

- Effective dose: **20 mSv**
- Equivalent dose to the lens of the eye: **20 mSv**
- Equivalent dose to the skin: **500 mSv**
- Equivalent dose to extremities: **500 mSv**

Public Exposure:

- Effective dose: 1 mSv
- Lens of the eye: 15 mSv
- Skin: 50 mSv

Students / Trainees (16–18 years)

- Effective dose: **6 mSv**
- Lens of the eye: **15 mSv**
- Skin: **150 mSv**
- Extremities: **150 mSv**

For students under 16 years of age, public dose limits apply. For students over 18, occupational dose limits apply.

All limits refer to the **sum of doses from all exposure pathways** (external and internal) from all registered or licensed practices.

Basic Ways to Protect Against Radiation

There are 3 basic ways to protect against external contamination by radiation:

- By distance (increasing the distance decreases the irradiation proportionally to the power of distance).
- By shielding, which effectively absorbs the given type of radiation.
- By decreasing the time of manipulation with the source.

Time

“Time” refers to how long a person remains near a radiation source. The longer you stay, the higher the dose received. Therefore, minimize the time spent near the source to only what is necessary to complete the task. If radiation levels are elevated:

- Perform the required work as quickly as practical.
- Leave the area immediately afterward.

Example: Staying in the sun all day leads to sunburn, while a short stay is far less harmful. Exposure time matters.

Distance

“Distance” refers to how close a person are to a radioactive source. Increasing the distance significantly reduces the dose, following the inverse square law for point sources. Example: Sitting close to a fireplace exposes you to intense heat; moving across the room reduces the intensity. The farther you are, the lower the radiation intensity.

Shielding

“Shielding” involves placing material between a person and the radiation source. Its effectiveness depends on the type and energy of radiation.

- A sheet of paper can stop alpha particles.
- A few millimetres of metal can attenuate beta radiation.
- Dense materials such as lead or thick concrete are required for gamma or X-ray protection.

Some radionuclides emit multiple types of radiation, requiring combined shielding approaches.

CHAPTER 10: DOSIMETRIC TERMINOLOGY, QUANTITIES, AND UNITS

Dosimetry is a set of knowledge related to the measurement of ionising radiation for the purpose of quantifying certain radiation effects. Dosimetry usually involves the estimation of absorbed dose or related quantities (exposure, kerma) originating from the interaction of radiation with matter. Radiation dosimetric response functions are usually expressed by dose-effect relationships that provide a mean estimate of the upper and lower limits of these dosimetric effects. Dosimetry is therefore a fundamental requirement in all radiation applications, particularly in radiation therapy and radiation protection.

The concepts, quantities, and units of dosimetry were defined by the International Commission on Radiation Units and Measurements (ICRU 1980). The relevant definitions of quantities can be found in the STN ISO 80000-10:2009 standard. All relevant quantities used for measurements and simulations can be divided into the following areas:

1. quantities and units characterising sources of ionising radiation (activity, half-life, source emission, energy of emitted particles, etc.),
2. quantities describing the ionising radiation field and its propagation through space (fluence, flux, etc.),
3. quantities describing the interaction of ionising radiation with matter (effective cross-section, linear attenuation coefficient, etc.),
4. quantities for quantifying radiation effects, dosimetry quantities, exposure assessment, and radiation protection (radionuclide intake, dose, effective dose, commitment, etc.).

The Quantities Characterising Sources of Ionising Radiation

As it is generally known, ionising radiation can be produced by various sources – radionuclides, X-rays, accelerators, nuclear reactors, and even from space. For each such source, it is important to have quantities that allow the amount of radiation emitted from the source to be quantified, and for a radionuclide source, the amount of radionuclide. Mass is not used to characterize the amount of radionuclide, as is the case with other substances, because radionuclides are usually embedded in another carrier substance or mixed with daughter nuclides formed after transformation, and measuring the mass of radionuclides would be problematic in this case. The quantity used is activity, which expresses the frequency of transformations.

Activity

Activity expresses the ratio of the mean value of the number of spontaneous nuclear transformations from a given energy state dN occurring in a quantity of radionuclide during a elemental time interval dt and this time interval (definition STN ISO 80000-10:2009).

$$A = \frac{dN}{dt} \tag{10.1}$$

The law of radioactive decay states that activity is proportional to the number of radioactive nuclei according to the relationship: $A = \lambda N$. The main unit of activity A is the reciprocal second s^{-1}. The main unit of activity according to SI is called the becquerel (Bq). Since λ is a constant for a given type of nucleus, activity will depend only on the number of radioactive nuclei. Therefore, activity A will decrease exponentially as the number of nuclei changes.

$$A = A_0 e^{-\lambda t} \tag{10.2}$$

where A_0 is the initial activity, i.e., the activity at time t = 0.

The Quantities Describing Radiation Propagation and Quantification of Radiation Effects

Ionising radiation loses its energy through interactions when passing through a material environment. This results in changes in structure and composition, which depend on the energy absorbed (transferred) by the material at a given location. The energy losses of radiation at a given location may not be absorbed by the material at that location. The difference can be emitted, for example, in the form of bremsstrahlung from electrons outside the volume under consideration. The amount of energy absorbed by the material is expressed by the absorbed dose.

Absorbed Dose

The **absorbed dose** [Gy = J·kg^{-1}] at a given point for each IR is the ratio of the average transferred energy $d\bar{\varepsilon}$ substance in the volume element dV and its mass dm.

$$D = \frac{d\bar{\varepsilon}}{dm} \tag{10.3}$$

The main unit of dose is 1 joule per 1 kilogram = 1 J.kg-1 = 1 $m^2 s^{-2}$. Its name is Gray (Gy): 1 Gy = 1 J.kg^{-1}. In the past, the unit of dose was 1 rad (abbreviation of "radiation absorbed dose"). The relationship between them is 1 rad = 10^{-2} Gy. The transferred energy ε has the SI unit joule - J and is defined by the relationship:

$$\varepsilon = R_{in} - R_{out} + \Sigma_{Qen} \tag{10.4}$$

where R_{in} is the sum of energies (excluding rest energy) of all charged (directly ionising) and uncharged (indirectly ionising) particles entering a given volume, R_{out} is the sum of energies (excluding rest energy) of all charged and uncharged ionising particles exiting a given volume, and Σ_{Qen} is the sum of all changes (with a positive sign for an increase and a negative sign for a decrease) of the energy equivalent of the rest mass of nuclei and elementary particles in each nuclear transformation occurring in a given volume.

The dose describes the transfer of energy over a certain period of time. The term dose is used in connection with any type of radiation and any absorber (irradiated object). The dose depends on the irradiated material; therefore, for accuracy, the substance to which it relates is also specified, e.g. D_{air} - air, D_{tiss} - tissue. The dose, therefore, characterizes only the energetic effects of radiation. When assessing the biological effects of different types of radiation, we use it only as a guide. The absorbed dose (at a specific point and in a specific environment) is the most interesting dosimetric quantity for most users of ionising radiation.

Since the biological effects of radiation depend to a large extent on the energy absorbed by the human body, the absorbed dose is a measure of the degree of radiation damage to the body. The use of this unit is advantageous because the amount of absorbed energy is easily measurable, e.g. by calorimetric methods. However, it should be noted that the biological effects of radiation differ for different types of radiation, even though the body has absorbed the same amount of energy. When assessing the biological effects of radiation, it is therefore necessary to know not only the amount of energy transferred (absorbed), but also the manner of its transfer and the type of radiation by which this energy was transferred.

The immediate situation is described by the dose rate. The **absorbed dose rate** (dose rate) expresses the increase in dose dD in the time interval dt divided by the time interval dt.

$$\dot{D} = \frac{dD}{dt} \tag{10.5}$$

The main unit of dose rate is 1 joule per second per 1 kilogram = 1 Watt per 1 kilogram = 1 $J.s^{-1}.kg^{-1}$, i.e. $Gy \cdot s^{-1}$. Its dimension is m^2s^{-3}.

The transfer of photon energy to matter takes place in two steps. First, the energy of the primary photons is converted into the kinetic energy of secondary electrons or into the rest and kinetic energy of electron-positron pairs. This energy is then transferred in the vicinity of the interaction site, which manifests itself in the ionisation and excitation of atoms. Part of the energy can be carried over considerable distances by scattered Compton photons, characteristic X-rays, bremsstrahlung from secondary electrons, or annihilation photons.

Kerma

The dose refers to the transfer of energy to a substance at a given location from the charged particles to the particles of the substance. If the primary particles are neutral, the transfer of energy to matter must be preceded by interaction with the material and creation of charged particles, on which the kinetic energy is transferred. This step is described by KERMA (Kinetic Energy Released in MAtter). It therefore only applies to uncharged particles and to a given material.

Kerma K is the ratio of the mean value of the sum of the initial kinetic energies dE_k of all charged particles released by indirectly ionising particles in a given volume of the relevant substance, to the mass dm of the substance contained in this volume.

$$K = \frac{dE_k}{dm} \tag{10.6}$$

dE_k is the total initial kinetic energy of all charged particles in the volume dV released by uncharged radiation particles. The main unit of kerma is 1 joule per 1 kilogram = 1 J.kg^{-1}. The unit is called gray (Gy).

Air Kerma is closely related to exposure, but is based on energy transfer rather than charge production. Its unit is the same as for absorbed dose. Air Kerma, apart from usually small corrections that take into account energy losses due to bremsstrahlung, is equal to the energy equivalent of exposure. While exposure is conceptually related to photon radiation, Kerma is defined for all types of non-ionising radiation.

Exposure

The ionising effects of radiation, i.e., the amount of electric charge created by radiation in a unit volume of air, are characterised by **exposure *X***. It is the ratio of the mean value of the sum of the electric charges dQ of all ions with the same sign, generated in a certain amount of air (after the flight of all electrons, i.e., negatons and positrons), released by the incident γ photons in a volume element of air and the mass dm of this volume of air.

$$X = \frac{dQ}{dm} \tag{10.7}$$

Ionisation caused by the absorption of bremsstrahlung emitted by secondary electrons is not included in the sum of electric charges Q. With the exception of this difference, the exposure according to the above definition is the ionisation equivalent of air kerma. Exposure is historically the oldest dosimetric quantity. Its disadvantage is that it is defined only for photon radiation in air. In radiation protection, it is gradually being replaced by Kerma. However, it is still often used in radiation metrology due to the accurate methodology of its absolute measurement.

The main unit of exposure X is 1 coulomb per 1 kilogram (C kg^{-1}). In the past, the unit roentgen R = 2.58 x 10^{-4} C kg^{-1} or 1 C kg^{-1} = 3876 R was used. Irradiation of 1 C.kg^{-1} creates 6.25·x 10^{18} ion pairs in one kg of air under normal conditions, absorbing energy of 2.125 x 10^{20} eV=34 J. One roentgen then represents the energy per kg of air or the absorbed dose in air of 34 x 2.58 x 10^{-4} J.kg^{-1} =8.77·x 10^{-3} J·kg^{-1} =8.77 mGy.

Other units were also derived from the roentgen, but they are no longer used in Slovakia, while they are common in the USA, Russia, etc. In radiation protection, the unit rem was used - the biological equivalent of an X-ray (X-ray equivalent man), defined as the dose of radiation that causes the same biological effect in humans as 1 R of X-ray radiation generated in an X-ray tube with a voltage of 250 kV.

The Quantities Used in the Assessment of Radiation Exposure
Dose Equivalent, Equivalent Dose

From a practical point of view, it is not enough to know the dose in order to assess the severity or probability of harmful effects on the human body that may be caused by radiation under unspecified conditions. In dosimetry, it was more advantageous to introduce another quantity that better characterizes the more significant harmful effects of radiation, especially the later stochastic effects. To express the differences in biological effectiveness of different types of ionising radiation or different irradiation conditions, quantities obtained by multiplying the absorbed dose by appropriate modifying factors are used in radiation protection. The quantity that takes all of the above factors into account is called the **dose equivalent *H***. The dose equivalent at any point in biological tissue is given by the relationship:

$$H = DQ \quad [Sv] \tag{10.8}$$

where D is absorbed dose [Gy] and Q is quality factor, [-]

For precise calculations, the dose equivalent is used, depending on the precise value of linear energy transfer L.

$$H = \int_L Q(L) D_L dL \tag{10.9}$$

D_L is the dose distribution according to linear energy transfer. The ionisation density during radiation transmission depends on the value of the linear energy transfer L. The boundary between low and high ionising radiation is around 10 keV/μm, where below 10 keV/μm the $Q(L)$ is equal to 1, between 10 and 100 keV/μm, the $Q(L)$ depends on the relation (0.32L-2.2) and above 100 keV/μm the $Q(L)$ depends on the relation (300 $L^{-0.5}$). X-rays and gamma rays are considered low ionising, while fast neutrons, protons, and heavy particles are densely ionising. The L values for different types of radiation used in radiotherapy are given in Table 10.1

Table 10.1: L - linear energy transfer for different types of radiation.

Type of radiation	L - linear energy transfer, keV/µm
250 kV X-ray	2
3 MeV X-ray	0.3
1 keV electrons	12.3
10 keV electrons	2.3
1 MeV electrons	0.25
14 MeV neutrons	12
Co^{60} **gamma rays**	0.3
heavy charged particles	100-200

The ICRP recommendation proposes a similarly defined quantity instead of the dose equivalent: the equivalent dose. The quality factor has been replaced by the radiation weighting factor w_R, which can be used to determine the equivalent dose in tissue:

$$H_T = \sum_R w_R D_{T,R} \quad [Sv] \tag{10.10}$$

where $D_{T,R}$ is the mean absorbed dose in biological tissue T caused by radiation of type R. The radiation weighting factor w_R expresses the different biological effects of different types of ionising radiation. The name of the main unit of dose equivalent and equivalent dose is sievert (Sv) = J.kg^{-1}.

Table 10.2: Values of the radiation weighting factor w_R.

Type of radiation and its energy	w_R (ICRP 60)	w_R (ICRP 103)
Photons of all energies	1	1
Electrons of all energies	1	1
Neutrons, energy E		Continuous function:
< 10 keV	5	$2.5 + 18.2e^{-[\ln(E_n)]^2/6}, E_n < 1MeV$
10 keV - 100 keV	10	
100 keV - 2 MeV	20	$5.0 + 17.0e^{-[\ln(2E_n)]^2/6}, 1\ MeV < E_n < 50MeV$
2 MeV - 20 MeV	10	
> 20 MeV	5	$2.5 + 3.25e^{-[\ln(0.04E_n)]^2/6}, E_n > 50\ MeV$
Protons > 2 MeV	5	2
α particles, fragments, heavy nuclei	20	20

Effective Dose

The effective dose is a quantity introduced for the assessment of radiation protection. Its main use is for the planning and optimisation of radiation protection and for proving that dose limits have not been exceeded for the purposes of supervisory authorities. The **effective dose *E*** is the sum of the equivalent doses H_T in all organs or tissues multiplied by the relevant tissue weighting factor w_T.

$$E = \sum_T w_T H_T \quad [Sv] \tag{10.11}$$

The primary limit in radiation protection is the effective dose limit. Effective dose limits apply to the total effective dose in a given calendar year E, which is calculated as the sum of the effective dose from external exposure and internal exposure expressed in terms of **effective dose commitments** from individual intakes of radioactive substances by inhalation and ingestion in a calendar year from all sources of ionising radiation to which persons working with radiation sources or members of the public are exposed.

$$E = E_{extrnal} + E_{ing} + E_{inh} \tag{10.12}$$

The dose commitment is therefore assigned to the year in which internal contamination occurred (E_{ing}, E_{inh}), even though the exposure is calculated and may actually last for a longer period (we calculate 50 years for workers and 70 years for the general public). The effective dose from external exposure for workers with ionising radiation sources is obtained from personal dosimetry data.

Table 10.3: Tissue weighting factor w_T

Tissue, organ	Tissue weighting factor w_T (ICRP60)	Tissue weighting factor w_T, (ICRP103)
Gonads	0.20	0.08
Red bone marrow	0.12	0.12
Large intestine	0.12	0.12
Lungs	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Mammary gland	0.05	0.12
Liver	0.05	0.04
Oesophagus	0.05	0.04
Thyroid gland	0.05	0.04
Skin	0.01	0.01
Bone surfaces	0.01	0.01
Salivary gland	-	0.01
Brain	-	0.01
Other organs and tissues	0.05	0.12

PART TWO

Economic and Managerial Foundations

CHAPTER 11: FINANCIAL STATEMENTS FOR ANALYSIS

Financial statements under single-entry and double-entry bookkeeping Transformation Process (TP)

The transformation process represents a dynamic phase in the company's development, encompassing structural, organizational, financial, and ownership-related changes implemented to ensure long-term stability, sustainable profitability, and future growth. This process typically involves a strategic reorientation of resources, optimization of production capacities, digitalization of internal processes, or a change in the company's governance and operational model.

Within the context of financial and economic analysis, the transformation process must be evaluated not only in terms of its course and specific actions undertaken but also in terms of its measurable results—in particular, its impact on the company's performance indicators, cost efficiency, and competitiveness. Given the limited amount of publicly available information, the assessment of the company's transformation is based primarily on observable outcomes reflected in key financial ratios (e.g., profitability, liquidity, leverage) and in trends of growth and stability.

The transformation process thus serves as an essential analytical framework for understanding how effectively the enterprise adapts to market conditions, maintains financial equilibrium, and achieves continuous value creation over time.

Analysis of the Company's Financial Situation

A comprehensive financial analysis is a crucial instrument for assessing the company's performance, financial health, and sustainability. This analysis relies primarily on financial statements (FS), which serve as the fundamental source of quantitative information about the entity's assets, liabilities, equity, revenues, and expenditures.

Financial Statements (FS)

Financial statements are prepared either under Slovak accounting legislation or in accordance with International Accounting Standards (IAS) and International Financial Reporting Standards (IFRS). The dual approach allows for both local compliance and international comparability of financial data.

From an academic perspective, it is essential to evaluate whether the financial statements are materially, temporally, and formally correct, meaning that they accurately reflect the company's financial position, performance, and cash flows without misstatement or distortion.

Analytical Value of Financial Reporting

The analytical interpretation of financial statements is based on three core documents:

- The Balance Sheet, which captures the company's assets, liabilities, and equity at a specific point in time and provides a snapshot of its financial structure and solvency.
- The Profit and Loss Statement (Income Statement), which measures operational performance and profitability by comparing revenues and expenses over a defined accounting period.
- The Cash Flow Statement, which illustrates the movement of cash and cash equivalents, reveals the company's liquidity and ability to finance operations and investments.

For more comprehensive insights, a three- or four-balance financial reporting system may be applied, integrating the statement of changes in equity as an additional analytical component.

Analytical Techniques

A horizontal analysis examines the development of individual items in the financial statements over time, identifying growth tendencies and structural changes, whereas a vertical analysis assesses the proportional relationships among items within a single report, allowing for evaluation of internal efficiency and cost allocation.

Together, these analytical tools form an integrated framework for interpreting the financial position and dynamics of the company. They support informed managerial decision-making and provide a basis for strategic financial planning in line with both national and international accounting principles.

Financial Statements (FS) under Slovak legislation

The accounting and reporting system of business entities in the Slovak Republic is governed by the Accounting Act No. 431/2002 Coll., effective from 1 January 2003. This Act regulates the scope, method, and verifiability of bookkeeping, and sets the framework for the preparation and presentation of financial statements (FS).

Key Provisions of the Accounting Act

According to § 2, the Act defines essential accounting concepts such as *assets, liabilities, revenues, costs, economic benefits, income, expenses, economic result, property, and obligations*. Under § 7, every accounting entity is required to maintain financial statements that provide a true and fair view of the entity's financial position and results of operations.

Pursuant to Section 9 (1), accounting entities must apply the double-entry bookkeeping system, except for certain entities such as civic associations, communities of apartment owners, non-investment funds, hunting organizations, and churches (as defined in paragraph 2).

Entities are further obliged to prepare individual financial statements according to Sections 17 and 18, while § 22 specifies the requirements for the consolidation of financial statements for groups of accounting entities.

Purpose and Quality of Financial Statements

Financial statements represent a structured presentation of accounting information, intended for use by owners, management, financial institutions, potential investors, and business partners. The information contained in financial statements must be useful, relevant, comprehensible, comparable, and reliable, allowing users to make informed economic decisions.

Structure and Components of Financial Statements

Under Slovak legislation (Act No. 431/2002 Coll., Sections 17–18), the double-entry bookkeeping system requires three general components:

- Balance Sheet,
- Profit and Loss Statement,
- Notes to the Financial Statements (including an equity review and a cash flow report).

According to IAS 1 – Presentation of Financial Statements, financial reporting typically includes:

- a statement of financial position (balance sheet) at the end of the period,
- a statement of comprehensive income for the period (as one or two statements),
- a statement of changes in equity,
- a cash flow statement,
- explanatory notes,
- a statement of financial position at the beginning of the earliest comparative period (when retrospective adjustments or reclassifications are made).

Analytical Relevance of Financial Statements

Financial statements reveal the conditions of the transformation process within the enterprise. They provide insights into:

- the composition and sources of assets,
- the company’s production potential and liquidity,
- the relationship between profitability and risk, and
- the impact of the financial structure on the cost of capital.

Non-current assets typically generate higher returns than current assets, while the structure of current assets influences the liquidity and short-term solvency of the enterprise. The composition of financial resources is affected by their cost, as short-term debt capital is generally cheaper than long-term financing.

Changes in Financial Reporting (2014–2015)

In 2014, the model of financial statements for double-entry accounting entities underwent significant reform. Key changes included:

- The reclassification of own shares and ownership interests to the asset side as short-term financial assets, instead of their previous treatment as an equity-reducing item on the liability side (formerly line 070).
- Introduction of definitions such as parent entity, subsidiary, group, affiliated entities, participating interests, and associated entities, relevant for consolidated reporting.
- In line with the abolition of extraordinary revenues and expenses, the notes now refer to income and costs of exceptional scope.

In the 2014 profit and loss statement, several items (e.g., *trade margin, production, and consumption indicators*) were removed, and only added value is now directly presented, defined as:

Added Value = Trade Margin + Production – Production Consumption

A new line labelled "Net Turnover" was introduced, representing revenues from the sale of products, goods, and services after discounts.

Further adjustments, according to §4bg (3) and (4) of the new Financial Statement Measure, modified the method of reporting data for both the current and immediately preceding accounting period.

Summary of Major Structural Changes

- Reclassification of entities in consolidated groups as related or associated entities.
- Division of financial assets into long-term and short-term categories.
- Inclusion of bank accounts with a maturity of over one year under long-term financial assets.
- Own shares redefined as part of short-term financial assets.
- More detailed reporting of long-term and short-term receivables and payables.
- Financial accounts limited to cash and bank accounts.

- Revised structure of equity, including separate lines for statutory and other funds created from profit.
- Addition of a Net Turnover line reflecting the 2015 classification of entities into micro, small, and large categories.
- Inclusion of aggregate totals (e.g., Total Income from Economic Activity, Total Costs of Economic Activity, etc.).
- Removal of Business Margin, Production, and Consumption lines.
- Extraordinary revenues and expenses are no longer reported.

Requirements for Financial Statements under IAS / IFRS

The conceptual framework establishes the theoretical foundation upon which the preparation and presentation of financial statements are based. It defines the objectives, qualitative characteristics, and basic principles that ensure the usefulness and consistency of financial information across different entities and reporting periods.

Objective of Financial Statements

The primary objective of financial statements is to provide relevant and reliable information about the financial position, performance, and changes in the financial condition of a company. This information serves as a key source for assessing the company's economic resources, its financial structure, its liquidity and solvency, and its capacity to adapt to environmental and marketchanges. In this sense, financial statements form an essential instrument for users—owners, investors, creditors, and other stakeholders—to evaluate both past performance and future prospects of the enterprise.

Performance and Basic Assumptions

The concept of performance reflects how effectively an enterprise uses its available resources to generate income and create value. The preparation of financial statements is guided by two fundamental accounting assumptions:

- the accrual basis, which requires that the effects of transactions and events be recognized when they occur, not when cash is received or paid; and
- the going concern principle (principle of continuous duration), which assumes that the entity will continue its operations for the foreseeable future and has neither the intention nor the need to liquidate or significantly curtail its activities.

Qualitative Characteristics of Financial Statements

To achieve their objective, financial statements must meet certain qualitative characteristics that enhance the decision-usefulness of the information presented. These include:

- Clarity (understandability): the information should be presented in a manner that is comprehensible to users with reasonable knowledge of business and accounting;
- Relevance: the information must be capable of influencing users' economic decisions by helping them evaluate past, present, or future events;
- Reliability (faithful representation): financial data should faithfully represent economic reality, free from material errors or bias;
- Comparability: users must be able to compare financial statements across different periods and entities to identify trends and evaluate relative performance.

Although these characteristics are consistent with international practice, in the Slovak Republic, they are described in greater detail under national accounting regulations and interpretative guidance.

Content, Reporting Method, and Valuation

The content and structure of financial statements are determined by accounting standards, which define the method of reporting and the valuation of their key elements—assets, liabilities, equity, revenues, and expenses. Each of these elements contributes to a comprehensive picture of the company's financial position and performance.

Valuation methods applied in the Slovak accounting framework include historical cost, fair value, and amortized cost, depending on the nature of the asset or liability. Proper valuation ensures that financial statements provide an accurate and objective representation of the company's economic reality.

Capital and Its Preservation

The conceptual framework also introduces the concept of capital and its preservation, distinguishing between two approaches:

- Financial capital maintenance, which focuses on the preservation of nominal monetary capital and considers profit as earned only when the closing net assets exceed the opening net assets, excluding owner transactions; and
- Physical capital maintenance, which focuses on the capacity of the entity to maintain its productive capability, recognizing profit only after this capacity has been preserved.

This distinction is fundamental for evaluating the sustainability of a company's growth and ensuring that reported profits represent a genuine increase in value rather than the erosion of capital.

Key formal differences between Slovak accounting regulations and IFRS

Financial Statements under IAS / IFRS

The preparation and presentation of financial statements in accordance with International Accounting Standards (IAS) and International Financial Reporting Standards (IFRS) represent an important dimension of corporate reporting within the Slovak accounting framework. These standards provide a globally recognized basis for the preparation of financial information, enhancing its transparency, comparability, and reliability across national borders.

Entities Affected by IFRS

In the Slovak Republic, approximately 160 companies prepare their financial statements in accordance with IFRS. The legal framework for this obligation is defined in Accounting Act No. 431/2002 Coll., Section 17a, which specifies the entities that are either required or permitted voluntarily to report under IFRS.

Mandatory IFRS Reporting

The obligation to apply IFRS applies to several categories of entities based on their nature of activity or size criteria.

Defined Entities

Mandatory application of IFRS covers:

- Banks and branches of foreign banks;
- Management companies;
- Insurance and reinsurance companies (excluding health insurance companies);
- Pension administration companies and supplementary pension funds;
- The stock exchange;
- Accounting entities established under a special legal regulation;
- Branches of insurance undertakings from other EU Member States.

Entities Meeting Size Criteria

In addition to the defined institutions, IFRS reporting is mandatory for any accounting entity that has met at least two of the following criteria for two consecutive accounting periods:

- Total assets exceed EUR 170,000,000 (gross value);
- Net turnover exceeds EUR 170,000,000 (net turnover = revenues from the sale of products, goods, and services after discounts, plus other revenues, minus discounts to entities engaged primarily in other types of business activity);
- The average number of employees exceeds 2,000 in each accounting period.

Voluntary IFRS Reporting

Certain entities may voluntarily adopt IFRS reporting if they meet specific conditions or operate within regulated markets. These include:

- Entities that have issued securities admitted to trading on a regulated market;
- Payment institutions, electronic money institutions, securities dealers, or branches of foreign securities traders, provided they are not simultaneously classified as banks, management companies, or branches thereof;
- Other entities, such as successor accounting units or newly established subsidiaries, whose parent company prepares financial statements in accordance with IFRS.

Continuity of IFRS Reporting

Once an entity—whether under mandatory or voluntary status—has begun to prepare its individual financial statements in accordance with IFRS, it is required to continue doing so, even if the initial conditions for the obligation or eligibility cease to exist in subsequent periods. This ensures consistency and continuity in financial reporting and facilitates long-term comparability of financial data.

Conceptual and Regulatory Basis

Financial statements prepared under IFRS must adhere to:

- The Conceptual Framework for Financial Reporting, which sets out the underlying objectives, qualitative characteristics, and elements of financial statements (often referred to as the *Financial Reporting Framework*); and
- The relevant International Accounting Standards (IAS) and International Financial Reporting Standards (IFRS), as issued and periodically updated by the International Accounting Standards Board (IASB).

These principles collectively ensure that IFRS-based financial statements provide a true and fair view of the company's financial position, performance, and cash flows, and that they remain comparable on both domestic and international markets.

Basic differences in financial statements prepared by SAS and IAS / IFRS:

There is a different hierarchy in Slovakia where the law is superior to standards. IFRS has a conceptual framework as a theoretical basis and individual standards that have priority in case of conflict.

In the structure of the FS (according to IFRS, the structure is more structured, the statement of financial position at the end of the period, (balance sheet) - assets - the economic resource controlled by the enterprise, the result of past events - current non-current, liabilities, equity - difference in assets and liabilities (depends only if the equity is higher at the end of the period compared to the beginning.

The balance sheet is renamed to the Statement of Financial Situation, although the balance sheet name can still be used. This is the primary source of information about the company's financial situation. It expresses the basic components of the enterprise: Assets, liabilities, and equity. Property is understood to be the economic resource controlled by the enterprise as a result of past events and from which it is expected that the enterprise will benefit from it in the future. Property ownership is not essential. The basic breakdown of assets is current and non-current. Current assets meet the following criteria:

- it is expected to be sold or consumed within the normal operating cycle,
- it is held by trading purposes,
- its implementation is expected within 12 months of the closing date,
- it is cash or cash equivalent with unlimited use.

Other assets can be considered as non-current.

Commitment is the current obligation of the enterprise that arises from past events and is expected to result in an outflow of funds from the enterprise.

Commitments are divided into current and non-current.

The current obligation meets the following criteria:

- it is expected to be repaid in the normal operating cycle,
- it is held for trading purposes,
- its repayment is expected within 12 months of the closing date.

Other obligations are considered non-current.

Equity represents the difference between assets and liabilities. Equity may be classified in the balance sheet as shareholders' equity, share premium, retained earnings, reserves, etc.

This is a financial concept of equity. The financial concept is effective when users of financial statements are interested in maintaining the nominal value of the invested capital.

We also know the physical concept of equity, which is its reproductive capacity. Equity is considered to be the production capacity of the enterprise, expressed, for example, in production units per day.

The revised standard requires disclosure of the balance sheet at the beginning of the comparative period in cases where the accounting unit applies a change in balance sheet policy.

The comprehensive income statement defines the overall result for the period as a change in equity. The report may be compiled differently:

- as a sum (profit and loss statement), all items plus other comprehensive income (all items),
- as a sum (profit/loss result), only one item from the statement plus other comprehensive income (all items).

Profit and Loss Statement can be compiled and presented as before. It is the primary source of information about the company's financial performance. Revenues represent an increase in economic benefits during the reporting period in the form of an inflow or increase in assets and a reduction in liabilities.

We distinguish between income from ordinary activities, which include sales, services, interest, dividends, etc...

Costs represent a reduction in economic benefits during the accounting period in the form of an outflow of assets or a liability, resulting in a decrease in equity, but other than a reduction related to the distribution of equity.

Costs are divided into those that arise from ordinary activities, such as depreciation, wages, and losses that may or may not arise in the ordinary activities.

Costs are reported in the income statement when future economic benefits are reduced in the form of a decrease in the value of property or an increase in liabilities. Distinguishing between income and expenses from ordinary activities and other revenues and losses is important to predict the ability of an enterprise to generate cash and cash equivalents in the future.

The Statement of Changes in Equity is used to identify the causes that caused a change in equity in order to make strictly separate changes in equity related to the owner's transactions from changes that do not arise from transactions with owners.

For this reason, only changes related to owner transactions are presented in the statement of changes in equity.

The Cash Flow Statement is the primary source of information about changes in the financial position of an enterprise, its ability to generate cash and cash equivalents.

In IAS I, the statement is only briefly presented as part of the financial statements. Basic concepts, methods, and structures are given in IAS 7. There are no changes to this report. The cash flow statement under Slovak accounting standards is included in the comments, and it isn’t a separate statement.

Notes are a very important part of the financial statements. They contain the following information:

- how to prepare financial statements and specific accounting methods,
- information required by IAS / IFRS,
- additional information that is not presented in the reports,
- significant risks and uncertainty.

The comprehensive income statement does not have a parallel in the Slovak statement; Cash Flow Statement (most comparable to the SVK version) and the Statement of Changes in Equity are part of the notes, statement of financial position at the beginning of the earliest comparative taxation according to the Slovak legislation.

- in the reporting structure (only the minimum items have been determined under IAS / IFRS,different report designs are permitted),
- in the account definition. We have an economic or calendar year of 12 months. If the accounting period changes, according to IAS / IFRS can be an accounting period of 52 weeks, with a change of more than a year
- in the content of the notes (IAS / IFRS requires a more detailed explanation)
- in reporting of FS elements (assets, liabilities, equity, income, expenses):

- different valuation of assets, according to IFRS, it usually uses fair value, which is higher than the book value
- different criteria for the breakdown of assets and liabilities - SVK according to the useful life and valuation of the asset component, IFRS only respects the period of fixed assets => fixed tangible assets > 1 year
- A different approach to the use of compensation can be balanced by the profit and costs of the sale of tangible fixed assets, exchange gains and losses
- Possible different cost classification (according to IAS / IFRS, the cost may also be classified by function, extraordinary costs and revenues are not reported), ...
- Evaluation of the performance of a company, if it is based on a comprehensive result that also absorbs changes in equity without affecting the owner's
- Financial assets are included in the assets of the company as opposed to those solely in Slovakia.

CHAPTER 12: CORPORATE CAPITAL, TAXATION, DEPRECIATION POLICY

Corporate capital is the sum of financial resources tied to a particular asset. Capital Structure - How much capital do we need? - the need for capital is determined by the volume of assets; the structure of the total long-term capital of the company, which we finance by the company's long-term assets (equity + long-term debt capital) - the following factors affect the financial and capital structure of assets: - cost of capital (costs of equity and debt capital) - the amount and profitability of corporate earnings- the cost of financial difficulties- property structure of the company- the effect of inflation- the requirements of financial security and freedom- trying to maintain ownership of the business- the situation on the financial market

Cost of equity. For a business, there is a profit share that the owner expects and receives for investing capital in the enterprise. The cost of debt is the interest that an enterprise must pay to the lender- the amount of the interest rate varies according to the period of interest- in general, long-term loans are more expensive than short-term loans, as long-term loans are more risky for creditors- the rate of interest varies depending on how well the company is assessed- the lower the value, the longer the loan, because the risk premium increases in interest- we calculate the actual interest rate, taking into account the tax rate paid (1% tax rate)

The cost of equity is higher than the cost of debt because the owner's risk is higher than the creditor's risk- the creditor puts the funds into the company for a pre-agreed time.

Cost of Financial Difficulty. A company that has a high share of foreign resources will become more insolvent and is related to the departure of skilled workers (going bankrupt and restructuring in the future).

Enterprise Property Structure

The basic components of corporate assets are fixed and current assets, and each group has a number of items. In terms of the effect on the financial structure, the material composition of the assets is not so important, but the turnover of the individual asset items, whereby businesses try to respect the two funding rules:

The Golden Rule of Financing - The resources that cover the assets are available to the company for at least the time that the relevant component of the property is available for the company.

- This is a time consistency between resources and property ties (asset life).

Golden Balance Rule - Requires long-term assets to be financed by capital that the company has permanently or long-term available.

Inflation
1. Increases nominal interest on loans, and this interest rate reduces the tax base.
2. Favors borrowers and puts creditors at a disadvantage.
3. Business assets of a financial nature are depreciated.

Financial market situation
Is influenced by the owners' willingness to invest their resources and is also influenced by the ability to place bonds on the market or obtain credit.
The relationship of debt and equity capital should be 1:1.

External

Financial resources represent funds that flow into the enterprise from its external environment. These resources constitute the capital base necessary for initiating and sustaining business operations.

At the time of the company's establishment, capital is typically formed through the owner's initial contribution (original equity investment). Over time, this base may be expanded through additional owner contributions made during the course of business activity to support growth or restructuring.

The composition and form of capital vary depending on the type of business entity and its legal structure. In the case of joint-stock companies, capital may be raised through the issue of shares, which enables the concentration of financial resources from multiple investors. Alternatively, businesses may acquire capital through other financing mechanisms, such as venture capital or risk capital funding, which involve external investors providing funds in exchange for ownership participation or future returns.

Owner's deposits

In certain types of business entities, the law does not impose limits on the amount of capital contribution made by owners or partners. For example, in public companies (a.s.) and limited partnerships (k.s.), the amount of the initial deposit is not legally restricted. In contrast, in a limited liability company (s.r.o.), the law specifies a minimum registered capital of €5,000 and a minimum individual shareholder contribution of €750. These requirements ensure that each limited liability company has at least a basic financial foundation upon its establishment.

Nature of Shares and Corporate Ownership

A share represents a unit of ownership interest in a corporation. It entitles its holder to a proportionate claim on the company's assets and earnings, but does not imply direct ownership of the company's physical property. Shareholders, therefore, do not own corporations themselves; rather, they own shares issued by corporations.

Corporations are treated under law as independent legal persons—they can own property, enter into contracts, pay taxes, borrow funds, and be sued or sue in their own name. This legal personhood means that the corporation owns its assets, not its shareholders. For instance, the furniture, equipment, or office premises of a corporation belong to the company itself, not to individual investors.

When an individua holds, for example, 33% of the company’s shares, it is not accurate to claim ownership of one-third of the company’s assets. Instead, it is correct to say that the investor owns 100% of one-third of the issued shares. This distinction illustrates the separation of ownership and control, a fundamental concept in corporate governance. Shareholders have ownership rights through their shares, but they cannot unilaterally dispose of the corporation’s property or make managerial decisions.

Rights of Shareholders

Ownership of shares provides several key rights and privileges, including:

- the right to vote at general meetings of shareholders, typically influencing major corporate decisions.
- the right to receive dividends, which represent a portion of the company’s distributed profits, if and when declared by the board.
- and the right to transfer or sell shares to other investors on the capital market.

When a shareholder or group of shareholders holds a majority of shares, they gain proportionate voting power that allows them to influence or control the strategic direction of the company. This influence is primarily exercised through the appointment of the board of directors, who manage the company on behalf of shareholders.

This mechanism becomes especially evident during mergers and acquisitions, where the acquiring company does not purchase the target’s physical assets directly; instead, it acquires ownership by purchasing a controlling share of the target company’s stock.

The role of contributed capital at formation and during growth across legal forms; determination of the enterprise’s profit/loss, and factors influencing its level

Risk capital

Enters only very profitable sectors and only through funding funds. These are the first steps of the company to finance high-risk investment and development projects.

- venture capital funding is a special source of funding
- a small or start-up business that has a lack of internal resources
- interested only in projects with a profit of 30 - 35%

Risk capital types:

- Pre-financing - focused on financing innovative product development
- Financing business development is the most common
- Substitute funding - debt servicing of the enterprise
- Transaction Financing - financing part of businesses, mergers, and various forms of stock control buyout
- Protective fixation - is a contribution to a business that has financial difficulties and is in danger of being liquidated, engaging in this form when the chances of rescuing a business are backed up by a quality future growth program.

Profit financing

Profit = Revenue - Cost

Determination of the difference between the equity at the end and the beginning of the reporting period. The starting point for this method is the valuation of corporate assets, from which the amount of debt capital of the enterprise is deducted. It all depends on how business assets are valued. Valuation - reducing profits and creating a hidden reserve in the business. Valuation is done according to whether an enterprise needs profit (e.g., to look good to investors) or less profit (e.g., needs tax evasion).

Factors affecting profit level

- The volume of realized production depends on the volume of production, on the change of stock of finished products in stock, and from the moment of realization (in our issuance of invoice, in the world otherwise). Growth in production volume = profit growth (but not in proportion - profit is growing faster)
- The structure of realized production affects the level of profit, because the company usually produces several kinds of products for which there is a different profit, therefore the effort is to change the structure in favor of more profitable products.)
- The price of a unit of realized production affects the profit directly, e.g., when the price increases, profit increases if other conditions do not change - these are prices without VAT.
- The cost per unit of production realized affects indirectly

TAX

The Role of Taxation in the State Budget

Taxation represents one of the most important sources of revenue for the state budget, serving as a fundamental instrument for financing public expenditures and implementing government policy. A well-designed tax system fulfills two primary objectives:

- to secure sufficient financial resources for covering state spending and the operation of public institutions; and
- to support the realization of the state's economic and social policy, influencing income distribution, investment activity, and overall economic stability.

Principles of Tax Policy

In a market economy, tax policy is built upon the taxation of both natural persons (individuals) and legal persons (corporate entities). The tax system thus ensures that contributions to public finances are made equitably across different sectors of the economy, reflecting the principle of the ability to pay.

A key component of the Slovak tax framework is the Value Added Tax (VAT), governed by the Value Added Tax Act No. 595/2003 Coll., which entered into force on 1 January 2004. VAT, as an indirect tax, is levied on the added value created at each stage of production and distribution, representing a significant and stable source of state revenue.

Corporate Income Tax

In the case of corporate income tax, the tax base is determined by adjusting the company's accounting profit. It is reduced by deductible items—such as tax-recognized expenses, depreciation, or investment allowances—and increased by additional items, for instance, non-deductible costs or adjustments to reserves. This mechanism ensures that the final tax base reflects the company's real taxable income.

Economic Implications of Tax Rates

Empirical experience and fiscal theory suggest that lower tax rates may lead to higher overall tax revenues, a concept often associated with the Laffer Curve. This relationship reflects the idea that excessively high tax rates can discourage economic activity and reduce compliance, while moderate rates may stimulate production, investment, and consumption, thereby broadening the tax base.

Company self-financing

Self-financing represents a fundamental internal source of funding for enterprises, based primarily on the retention and reinvestment of profits. It strengthens the company's own capital base and contributes to long-term financial stability and independence.

Types of Self-Financing

Self-financing may take two principal forms:

- Apparent (Open) Self-Financing. This form arises from retained earnings explicitly recorded in the company's financial statements. Profits are not distributed to shareholders as dividends but are retained within the company to finance future investment, expansion, or debt reduction.
- Hidden (Silent) Self-Financing. Hidden or silent self-financing occurs when a company reduces its reported profit by creating hidden reserves within its balance sheet. This approach involves deliberate valuation adjustments that lower the apparent profitability in financial reporting, while preserving funds internally.

Mechanisms of Profit Reduction

The creation of hidden reserves and thus the process of silent self-financing is typically achieved through:

- Overestimation of Liabilities, such as recording excessive provisions or reserves for potential risks; and
- Underestimation of Assets, such as undervaluing inventory, property, or receivables.

These practices result in lower reported profits, yet they retain financial resources within the company, enhancing its internal capacity for future financing.

Importance of Self-Financing

Self-financing plays a crucial role in maintaining the financial autonomy and stability of the enterprise. Its main advantages include:

- Strengthening the company's equity position and increasing its own capital base;
- Reducing dependence on external (debt) capital, thereby minimizing financial risk; and
- Lowering the cost of acquiring external financing, since a strong equity base improves the company's creditworthiness and bargaining position.

Overall, self-financing supports sustainable growth and provides a buffer against market volatility, making it one of the most desirable forms of business financing in both theory and practice.

Depreciation policy

Depreciation is an accounting method of allocating the cost of a tangible asset over its useful life. Businesses depreciate long-term assets for both tax and accounting purposes. For tax purposes, businesses can deduct the cost of the tangible assets they purchase as business expenses.

Depreciation is often a difficult concept for accounting students as it does not represent real cash flow. Depreciation is an accounting convention that allows a company to write off the value of an asset over time, but it is considered a non-cash transaction.

The monetary value of an asset decreases over time due to use, wear and tear, or obsolescence. This decrease is measured as depreciation. Depreciation, i.e., a decrease in an asset's value, may be caused by a number of other factors as well, such as unfavourable market conditions, etc. Machinery, equipment, and currency are some examples of assets that are likely to depreciate over a specific period of time. The opposite of depreciation is appreciation, which is an increase in the value of an asset over a period of time.

Three main inputs are required to calculate depreciation:

- Useful life – this is the time period over which the organisation considers the fixed asset to be productive. Beyond its useful life, the fixed asset is no longer cost-effective to continue the operation of the asset.
- Salvage value (Residual value) – Post the useful life of the fixed asset, the company may consider selling it at a reduced amount. This is known as the salvage value of the asset.
- Purchase price of asset – this includes taxes, shipping, and preparation/setup expenses.

As we already know, the purpose of depreciation is to match the cost of the fixed asset over its productive life to the revenues the business earns from the asset. It is very difficult to directly link the cost of the asset to revenues; hence, the cost is usually assigned to the number of years the asset is productive.

Over the useful life of the fixed asset, the cost is moved from the balance sheet to the income statement.

Types of depreciation and methods of depreciation

Methods of Depreciation

The method of depreciation applied by an enterprise is selected based on the expected pattern of consumption of future economic benefits derived from a fixed asset. The choice of method must reflect the actual manner in which the asset contributes to revenue generation during its useful life.

Straight-Line Depreciation Method

The straight-line method allocates the cost of a fixed asset evenly over its useful life**,** assuming that the economic benefits derived from the asset are realized uniformly throughout its usage period. This approach is particularly appropriate for assets such as buildings or office equipment, where wear and tear occur consistently over time.

The rate of depreciation is determined as follows:

$\% = 100/n$

n = useful life

Depreciation per annum= purchase cost x rate of depreciation, where n represents the useful life of the asset (in years).

Declining Balance Depreciation Method

The declining balance method (also called the reducing balance method) applies a higher rate of depreciation in the earlier years of the asset’s life, with the amount of depreciation gradually decreasing over time. This method is appropriate for assets that lose their economic value more rapidly during the first years of operation, such as vehicles or technological equipment.

By accelerating the recognition of depreciation expenses, this method better reflects the actual decline in the asset’s productivity and provides a more conservative view of the company’s financial position in its early years.

Accumulated Depreciation

Accumulated depreciation represents the total depreciation expense that has been recorded against a fixed asset since it was placed into service. It is a contra-asset account that offsets the original cost of the asset in the balance sheet.

Accumulated depreciation applies to tangible fixed assets such as buildings, machinery, office equipment, furniture, fixtures, and vehicles. The rate of depreciation may be estimated using one of the following approaches:

Rate of depreciation (%) = 2 x (n-T + 1) / n x (n + 1)

Uneven Depreciation Methods

In the Slovak market economy, specific uneven depreciation methods are recognized to account for assets that do not generate economic benefits uniformly over time.

A commonly applied example involves splitting the purchase cost of an asset into two parts:

- Two-thirds (2/3) of the purchase cost is depreciated using the straight-line method, and
- One-third (1/3) of the purchase cost is depreciated as follows:
    - 10% per annum during the first to third year,
    - 3.33% of the purchase cost in the fourth year.

This structure allows for faster depreciation in the initial years, better reflecting the accelerated consumption or obsolescence of certain types of assets, while still ensuring that the total depreciation aligns with the asset's expected economic life.

CHAPTER 13: TYPOLOGY OF ENTERPRISES

Enterprise in a market economy is the basic subject of doing business, which has its own typical signs and characteristics. Its position is the outcome of mutual interactions of the enterprise and its environment. Enterprise and its activity is object focused that mean enterprise objects create the starting point of entrepreneurial strategy. Enterprise existence is limited by the life cycle of the enterprise, which begins with the birth and finish as the death of the enterprise. Enterprise could be, according to Commercial Code (Act 513/91), determined as a is a system of tangible items (machines, buildings, equipment), intangible items (patents, invention, design, know-how, software, valuable rights, trade marks) and personnel items (owner, employees...) which belong to enterprise and it tries to use them effectively in its entrepreneurial activity with the aim to be competitive and sustain on the market – to have enough amount of own customers. To the intangible items of property, we could also add items which are part of every enterprise, represent it and belong to the general value of the property, e.g.:

- Business name: it represents the name of the enterprise under which the entrepreneur provides legal activities in business.
- Good reputation, event. Goodwill: represents the value of the good name of the enterprise,
- Know-how: represents the value of professional knowledge, eventually consulting in the area of technological processes, the recipe of production, and so on.
- Trade mark: registered brand, etc.

Entrepreneurship could also be understood as the economic activity of a subject (individual person, company) focused on the achievement of profitability (return of invested resources, ability to create profit) and also on the achievement of economic effects, eventually the objectives of the enterprise. Enterprises could be grouped or divided according to various criteria. The most frequent criteria of enterprise classification are in accordance with:

- Ownership
- Sector and economic segment
- Size
- Technical and organizational characteristics
- Final product characteristics or
- Legal form

This enterprise classification into individual groups is called enterprise typology.

Character of final product as the **result of enterprise activity** (final outcome of the enterprise activity is their products or services), which is why enterprises are divided into:

- production enterprises: primary production - agriculture, fishery, secondary production – producing products for investment (machines, tools), consumer products (food, clothes, and magazines)
- enterprises of services (not productive area) – commercial, transport, bank, insurance, accommodation, etc.

Another criterion is classifying enterprises according to **sectors of the national economy** into:

- Primary (basic industry) Agriculture, Fishery, Forest industries
- Secondary (construction/production industry), Manufacturing industry, Building industry
- Tertiary (Material services) Services, Logistics, Commerce
- Quarterly (Services of public character - state), Military services, Justice, Public administration
- Quinty (Development services) System of education, Health care system, Culture

Economic sector, enterprises are dividing enterprises on entities doing their activity in these sectors: agricultural, forestry, industrial, construction, transport, insurance, etc.

Technical and organisational characteristics of enterprises could be classified according to four additional criteria:

- *Production type* (Mass production, Series production, Piece/individual production)
- *Enterprise specialization* (Subject specialization, Technological specialization)
- *Production concentration* (Horizontal concentration, Vertical concentration)
- *Production factor importance* (difficult/demanding material, difficult/demanding work, difficult/ demanding capital (investment)

According to the **size of enterprise**, we are able to classify enterprises in European Union countries into micro, small, medium, and large. The most important characteristics are the number of employees, turnover, or capital per year.

Table 13.1: Size of enterprises

Size	**Number of employees**	**Turnover/year**	**Capital/year**
Micro	till 10	till 2 mil. Eur	till 2 mil. Eur
Small	till 50	till 10 mil. Eur	till 10 mil. Eur
Medium	till 250	till 50 mil. Eur	till 43 mil. Eur

According to **ownership**, we can speak about these types of enterprises:

- Private (owned by the private individual or group of members)
- Public (ownership of the state, cities) is managed through state bodies and their lower structures.
- Mixed represent enterprises in which state bodies (cities and villages) and private bodies participate in management.

Another point of view is the division of enterprises according to (within ownership) family and other types of business. Their characteristics could be found in the table below.

Table 13.2: Characteristics of enterprises

Family business	Other business
More emotional	More rational
Their results are spontaneous and vital	Their results are planned and managed
Are more supporting and consistent	Are more confrontational
Appreciate the equality of relationships	More frequent is the subordinated relationship
Important are family relations	Appreciate the merits

According to **legal form** – we can speak about enterprises of individuals, personnel, or capital types of enterprises:

1. Companies of individuals (Sole trader / Sole proprietorship / Sole practitioner, Freelancer, Farmer (individual agricultural production)
2. Personnel enterprises (General Partnership, Limited Partnership)
3. Capital enterprises (Private limited company, Public limited company)
4. Other (Co-operative, State company, Foreign owner company)

Concerning individual legal forms we could describe them more in detail:

1. Sole trader

- Nature Person – receiving a certificate or licence
- Specified in Trade Code
- Registered in Trade Register

General conditions:

- Age 18+
- Competence for legal acts
- Legal innocence / without criminal record (in relevant areas)

Typology according to **professional requirements**:

- Subject to **Registration** – receiving certificate
  - Craft – needed skills from professional school (e.g., joiner, locksmith, butcher)
  - Requiring special professional qualification (e.g., civil engineering, metal-foundry, pressurized or gas equipment)
  - Free
- **Licensed** – receiving licence – needed qualification + reliability + optional (e.g., purchasing, selling, and renting guns/weapons; road transport; etc.)

Typology according to **business subject**:

- Business – purchasing goods
- Manufacturing – producing products
- Services – transporting

2. Self-employed farmer

- Natural Person – receiving certificate
- Specified in the Act for self-employed farming
- Registered in the Communal Register

3. Freelancer

- Natural Person – receiving a licence
- Specified in individual acts for the concrete freelance job

Figure 13.1: Classification of freelance jobs

4. General Partnership

- Legal Person / Legal Body
- Specified in the Commercial Code
- Registered in the Business Register / Registrar of Companies
- Formed by a min. of 2 partners
- Liability – unlimited for each partner, also unlimited for the partnership
- Established by signing the Partnership Agreement (the name, the object, the partners)
- Basic Capital – not a set minimum, but usually some participation is agreed upon
- Profit and Loss Distribution – equally between/among partners
- Not taxed as a unit – each partner administrates tax return individually
- Managing – each partner equally
- Advantages – easy to set up (capital), personal management, taxation
- Disadvantages – liability for debts (jointly and severally), capital (loans), mutual trust required (managerial conflicts)

5. Limited Partnership

- Legal Person
- Specified in the Commercial Code
- Registered in the Business Register
- Formed by a min. of 1 general partner + 1 limited partner
- Liability – unlimited for general partner(s), limited for limited partner(s), and unlimited for partnership
- Established by signing the Partnership Agreement
- Basic Capital – minimum contribution for each limited partner: €250 , And usually some participation of general partner(s) is agreed
- Profit and Loss Distribution – equally between two groups of partners; Inside groups: equally between/among general partners; Taxed for limited partners, then distributed according to participation
- Not taxed as a unit – each general partner administrates tax return individually
- Managing – general partner(s)
- Monitoring – limited partner(s)
- Advantages – capital, characteristics of general and limited partners, loans conformity

- Disadvantages – complicated profit distribution, setting up competencies, unlimited liability for general partner(s)

6. Limited Liability Company

- Legal Person
- Specified in the Commercial Code
- Registered in the Business Register
- Formed by a min. of 1 partner but a max. of 50 partners (not shareholders)
- Liability – limited for partner(s) and unlimited for company
- Established by signing the Partnership Agreement, Articles of Association
- Basic Capital – a minimum of €5000
- Profit and Loss Distribution – first taxed as a company/corporation tax, then obligatory reserve fund contribution, and then profit distribution according to participation
- Reserve fund – optional at the registration of the company, obligatory after the first profitable year, 5% PAT/NP or 10% BC, obligatory each profitable year, 5% PAT/NP, until 10% BC
- Company Bodies: General Meeting – supreme body; Managing Director(s) – statutory body (act on the company's behalf); Supervisory Board – auditing body – optional
- Advantages – limited liability, 1 founder, managed by bodies (flexible)
- Disadvantages – taxation, reserve fund, loans (for smaller companies)

7. Joint Stock Company

- Legal Person
- Specified in the Commerce Code
- Registered in the Business Register
- Formed by shareholders; a min. of 1 legal person or 2 natural persons
- Liability – limited for shareholders and unlimited for the company
- Established by signing the Memorandum of Association, Articles of Association
- Basic Capital – a minimum of €25,000, divided among shares with a particular face/nominal value
- Shares – ordinary or preference, registered or bearer
- Profit and Loss Distribution – first taxed as a company/corporation tax, then obligatory reserve fund contribution, and then profit distribution according to share value

- Reserve fund – obligatory at registration of the company, 10% BC, obligatory each profitable year 10% PAT/NP, until 20% BC
- Company Bodies: General Meeting – supreme body, Board of Directors – statutory body (acts on the company's behalf), Supervisory Board – auditing body – obligatory
- Advantages – capital, loans, separated owners and management (bodies)
- Disadvantages – taxation, reserve fund, administration, conflicts (owners, bodies)

8. Co-operative

- Legal Person
- Specified in the Commerce Code
- Registered in the Business Register
- Formed by members; a min. of 2 legal persons or 5 natural persons
- Liability – limited for members and unlimited for the co-operative
- Established by signing the Articles of Cooperative
- Registered Basic Capital – minimum €1,250 , not set a minimum for each member
- Profit and Loss Distribution – first taxed as a company/corporation tax, then obligatory reserve fund contribution, and then profit distribution according to membership participation
- Indivisible fund – obligatory at registration of the company, 10% RBC, obligatory each profitable year, 10% PAT/NP, until 50% RBC
- Company Bodies: Membership Meeting – supreme body, Board of Directors – statutory body (acts on the company's behalf), Supervisory Commission – auditing body – obligatory
- Advantages – fulfilling interests, liability
- Disadvantages – taxation, indivisible fund, capital

Criteria for the legal form selection could be various, starting from liability, through flexibility till loan possibilities:

- Liability is connected with the guarantee, which is connected only with the own property of the company (as it is in Join Stock company or a limited liability company), or also with the private property of the owners (members of a general partnership, limited partners in a limited partnership, or all forms of individuals)
- Flexibility – another criterion which is connected with the ability to react what could be easier for more simple companies with less number of members.

- Management is the criteria which classify enterprises on personnel (where running of business is directly connected with owners) and capital types of enterprises (with professional management)
- Capital needs, thanks to the more complicated structure, request on basic capital and compulsory fund creation (reserve or indivisible fund), this criteria could also be important in the managerial decision about the selected legal form.
- Loan possibilities and accessibility of loans are connected more with more complex and structured companies, where it seems to be easier to obtain a loan or any financial support.

In the nuclear energy business, the primary legal form for operators of nuclear facilities is a corporate body (a company or a utility), which can be either state-owned or privately owned. The specific structure is heavily influenced by national law and government policy, with key considerations being limited liability, regulatory compliance, and project financing.

Regardless of the specific corporate structure, all entities involved in the nuclear energy business must adhere to a strict and comprehensive legal and regulatory framework that includes:

- Nuclear Liability: A special regime of strict liability is imposed on the operator in the event of a nuclear incident. This liability is channelled to the operator and is limited in amount and time, which is designed to ensure protection for victims while making projects insurable and financially viable for the industry.
- Licensing and Regulation: The entity must obtain various licenses (e.g., construction permits, operating licenses) from an independent national regulatory body (e.g., the U.S. NRC or the UK ONR). Only a corporate body can typically hold a site licence.
- Safety and Security: The organizational structure must prioritize a strong safety culture and adhere to national and international safety standards and measures established by bodies such as the IAEA and the OECD Nuclear Energy Agency (NEA).
- Finance and Decommissioning: Entities must demonstrate financial qualification and establish mechanisms for funding radioactive waste management and facility decommissioning.

CHAPTER 14: BUSINESS ASSETS

Carrying out entrepreneurial activity requires the existence of enterprise assets. The assets of an enterprise can be characterized as a set of things, monetary means, receivables, and other property values that belong to the entrepreneur and serve for conducting business.
The general definition of assets is provided by the Framework for International Accounting Standards (IAS):
"An asset is an economic resource which is the result of past periods, is controlled by the enterprise, and is expected to bring economic benefits to the enterprise in the future."
Act No. 431/2002 Coll. on Accounting, § 2, defines assets "as the assets of an accounting entity that are the result of past events, are almost certain to increase the economic benefits of the accounting entity in the future, and can be reliably measured; they are presented in the financial statements in the balance sheet or in the statement of assets and liabilities".
Assets organized according to types (e.g., buildings, land, machines, etc.) are collectively called assets (each component of assets – asset), and assets organized according to sources of financing (coverage) are collectively called liabilities (each individual source – liability).
A static overview (i.e., as of a certain date) of assets and their financial coverage is provided by the balance sheet (or statement of assets and liabilities).

Table 14.1: Basic Scheme of the Balance Sheet

Assets side	Liabilities side
A. Receivables for subscribed equity	A. Equity
B. Non-current assets	I. Share capital
I. Intangible non-current assets	II. Capital funds
II. Tangible non-current assets	III. Funds from profit
III. Financial non-current assets	IV. Retained earnings of previous years
C. Current assets	B. Liabilities
I. Inventories	I. Provisions
II. Long-term receivables	II. Long-term liabilities
III. Short-term receivables	III. Short-term liabilities
IV. Financial accounts	IV. Bank loans and assistance
D. Accruals	C. Accruals
TOTAL ASSETS	TOTAL EQUITY AND LIABILITIES

From the left side of the balance sheet – assets – one determines where, into which components of assets, funds were invested, and from the right side – liabilities – it is evident from where, from which sources, the funds originate.

Classification of Assets

The assets of an enterprise may be classified according to various criteria:

a) From the aspect of the functioning of assets in the transformation process

The functioning of assets in the circulation of the transformation process is the basis for the division into non-current and current assets.

Non-current assets operate in the economic cycle over the long term and gradually wear out; they do not change their form; they are often referred to as fixed, long-term, investment, or permanent assets.

Current assets change their form in the economic cycle, circulate in the asset cycle, are consumed once, and subsequently renewed.

b) From the substantive aspect

Assets may, from the substantive aspect, be divided into immovable and movable.

Immovable assets represent an existing property right to real estate. This right is usually recorded in an official document, such as a title deed or a lease contract. Immovable assets thus include all rights, property claims, and benefits related to ownership of real estate. In contrast, the term real estate includes the land itself, all things of a natural character situated on the land, as well as everything that has been built on the land, such as civil and engineering structures (roads, highways, bridges, residential and non-residential buildings). To distinguish immovable assets from real estate, some states use the terms realty (immovable goods and property rights) and personalty (movable goods).

Movable assets denote ownership rights to goods other than real estate. These goods may be:

tangible, e.g., machines, cars, computers, inventories, etc. Tangible movable property represents ownership of objects that are not permanently attached and can be moved;

intangible, e.g., receivables and patents.

c) From the time aspect

According to the time of ownership and use of assets in the enterprise, long-term and short-term assets are distinguished. The boundary between short-term and long-term is one year.

Long-term assets are assets whose period of usability, agreed maturity, or settlement in another manner (e.g., for receivables) is longer than one year.

Short-term assets are assets whose period of usability, agreed maturity, or settlement in another manner (e.g., for receivables) is shorter than one year.

Intangible Assets

Intangible assets are, above all, rights of industrial property, copyrights, or rights related to copyright, including computer programs and databases, projects, production and technological procedures, classified information, forest management plans, and technically and economically exploitable knowledge (know-how).

Tangible Non-current Assets

Tangible non-current assets include:

- buildings, apartments, and non-residential premises
- independent movable things and sets of movable things
- cultivation units of permanent crops

- basic herd and draft animals
- openings of new quarries and clay pits
- technical reclamation
- technical improvement
- land
- works of art
- collections
- objects of precious metals

These could be classified as (1) Depreciable non-current assets, and (2) Non-depreciable non-current assets.

Buildings, apartments, and non-residential premises.

The precise definition of these terms is governed by the Building Act. These include, for example, bridges, highways, railway and cable lines, pipelines, irrigation systems, mining structures, residential and non-residential buildings.

Independent movable things and sets of things, which have:

independent technical-economic purpose,

a period of usability longer than one year,

a price higher than €1,700.

These include, for example, machines, instruments, equipment, means of transport and inventory (furniture, artificial flowers, electrical appliances, etc.).

Cultivation units of permanent crops with a fertility period longer than three years

— for example, fruit trees, shrubs, hop gardens, vineyards, etc.

Basic herd and draft animals

— regardless of acquisition price, this includes adult breeding and productive animals for the purpose of economic use. Examples include horses (breeding, utility, breeding), cattle, goats, sheep, pigs, etc.

Openings of new quarries and clay pits

may be regarded as tangible non-current assets in the case that they do not increase the price of non-current assets, e.g., the enterprise's land.

Technical reclamation

— includes costs incurred by the enterprise for the modification of land, e.g., access roads.

Technical improvement

— these are expenditures for:

completed additions (increasing a structure),

annexes (expanding a structure),

construction alterations, changes to the external appearance and internal arrangement of a structure,

reconstructions — changes that cause a change in the use of the asset, a qualitative change of its performance or technical parameters,

modernization of the asset, which represents an extension of its equipment or usability by components that it did not originally contain.

A special part of tangible non-current assets consists of land, works of art, collections, and objects of precious metals.

Land includes agricultural land, forest land, and other land to which the enterprise has ownership rights or the right to manage the property.

Works of art include visual works and art objects. Collections represent a set of objects that depict the historical or technical development of a certain activity of the enterprise; movable cultural monuments. Objects of precious metals are those in which the precious metal forms a substantial component.

Long-term Financial Assets

Long-term financial assets are acquired by the enterprise, or owned, for the purpose of trading in them, or for the reason of long-term placement of free monetary means with the intention:

to permanently valorise them by means of dividends, interest, rent, etc.,

to control the given enterprise, or to acquire a significant influence over another enterprise,

to ensure a reliable, long-term business connection with a certain company.

Long-term financial assets represent assets whose period of usability, agreed maturity, or settlement in another way is longer than one year. Their most important components are securities and equity interests.

A security is a money-valued record in a legally prescribed form and format, with which rights are associated, in particular the authorization to demand certain property performance, or to exercise certain rights towards persons designated by law.

Wear and Depreciation of Non-current Assets

The basic characteristic of non-current assets (tangible and intangible) is that they are not consumed at once, but operate in the enterprise in the long term; they are used multiple times. However, by using the assets, change occurs, and these changes adversely affect their performance, functionality, as well as the quality of the work performed by them. Gradually, they become unusable and a process of disposal occurs.

Two types of wear are recognized:

physical (material) wear, which manifests itself by changes in the material substance of the asset and results in the loss of the utility value of the asset (i.e., the ability to fulfill and satisfy the needs for which it was produced),moral (value) wear, which arises due to technical and scientific progress, when new and more perfect machines, instruments, and equipment appear. The asset is then competed by assets with better construction, cheaper operation, and higher performance. With this wear, the asset loses its value.

Depreciation is the monetary expression of the wear of assets. It also expresses the gradual reduction of the value of long-term assets, which is projected into costs and into a certain quantity of new outputs.

Depreciation has these characteristic features:

its material basis is the wear of the asset,

it is contained in a certain volume of either created or already created outputs,
it is always expressed in monetary form,
it is a source of financing for the needs of the enterprise.

The amount of depreciation depends on two basic factors: price (acquisition, reproduction) and the level of the depreciation rate.

In business practice, one can encounter mainly tax and accounting depreciation. Each of them has a different legislative basis, a different purpose, different economic consequences, and is based on different assumptions.

The significance of tax depreciation for the enterprise is that it is the only legal method of getting the entry price of the asset into the so-called tax expenses. Tax depreciation is regulated by the Income Tax Act, and its calculation is the same for all business entities. Through tax depreciation, the taxpayer increases costs, reduces profit, and thereby reduces the tax. However, these depreciations do not at all reflect the degree of real wear of tangible and intangible assets.

The significance of accounting depreciation is that it takes into account the real wear of long-term tangible assets and affects the amount of profit before taxation by income tax. The entrepreneur chooses the depreciation period, the depreciation rate, and also the depreciation method so that the accounting depreciation expresses as precisely as possible the actual wear of the asset.

Current Assets

From the perspective of the division of enterprise production factors, the consumable factors, such as raw materials, semi-finished products, basic and auxiliary material, unfinished work-in-progress, finished products, etc., form one of the basic elementary production factors. These factors, together with receivables, financial assets, and goods, form the current assets of the enterprise.

A more detailed structure of current assets is formed by the following groups and their elements:

Inventories of material, work-in-progress, semi-finished products, finished products, and goods.

Receivables, which represent legal claims of the enterprise to expected payments for sold products or provided services, and can be divided into short-term (with maturity up to one year) and long-term.

Short-term financial assets, which consist primarily of cash (in bank accounts and in its cash register) and various valuables (cheques, vouchers, meal tickets, fuel coupons, telephone cards, revenue stamps, postage stamps).

Circulation and Turnover of Current Assets

The circulation of current assets is understood as the process of transformation, in which individual elements, respectively, entire groups of elements of current assets, pass through individual phases in the sphere of production and in the sphere of circulation, and return again to the initial phase.

The first phase of circulation begins in the sphere of circulation, where current assets are in the form of financial means. In the second phase, financial means are converted into production inventories, by which the circulation moves to the sphere of production.

In the production sphere, production inventories are gradually transformed into work-in-progress. Completion of production creates finished products. These then pass from the production sphere, after output technical control, to the warehouse of finished products, i.e., they pass into the sphere of circulation and are gradually sold. They again transform into financial means.
The process of continuously repeated and simultaneously ongoing circulation of current assets is called the turnover of current assets.

Indicators of Utilization of Current Assets

One of the basic conditions for the effective functioning of the enterprise is the best possible utilization of current assets. It can be monitored by means of the following groups of indicators:

- indicator of liquidity, i.e., the ability of the enterprise to settle its short-term liabilities in the given amount and time;
- indicator of the turnover period – the time during which current assets pass through their entire circulation; the objective is to shorten the turnover period as much as possible;
- indicator of the speed of turnover – the number of turnovers of current assets in a given time; the objective is to achieve the highest possible number of turnovers.

CHAPTER 15: BUSINESS COSTS

Every transformation process within an enterprise is inseparably linked with the consumption of various types of production factors, which become gradually worn out or are consumed instantaneously during the transformation process. These factors form part of the enterprise's assets, and their utilisation is associated with the work of employees engaged in production, management, and service processes.

Importance, Nature, and Origin of Costs

The objective of an enterprise is the efficiency of business activity, which is measured by the ratio of the outputs of the transformation process to its inputs. To achieve the best possible effect, the enterprise must influence both revenues, which represent outputs, and costs, which measure the inputs expended. **The costs of an enterprise represent the monetary valuation of the consumption of its production factors, including other purposefully expended resources necessary for the generation of business revenues**. Costs arise at the moment of consumption of the enterprise's production factor, which is decisive from the perspective of accounting records. From a managerial point of view, it is essential to realise that the very emergence of costs is influenced by previous managerial decisions. The incurrence of costs for a particular product or service is linked not only with its production but already begins with the technical preparation of production and concludes with the sale of the product or the provision of the service. The scope of costs is determined by the price at which the consumed production factor was acquired.

Costs within an enterprise are associated with its expenditures. However, costs cannot be equated with the term *expenditures*. Expenditures represent a reduction in the volume of the enterprise's financial resources and arise at the moment of payment. Given that costs, unlike expenditures, arise at the moment of consumption, there is a material and temporal discrepancy between costs and expenditures. The enterprise reports costs for the purpose of calculating the economic result as an outcome of business activity for a given period (in double-entry bookkeeping). Expenditures, on the other hand, are monitored in the enterprise due to their impact on the enterprise's cash flow and are reported in the statement of cash flows.

Classification of Costs

An enterprise requires the recording and monitoring of costs in various structures and from different perspectives for its decision-making. For this reason, there are numerous criteria determining different classifications of costs, and these costs frequently overlap.

Classification of Costs by Type

The classification of costs by type is used in financial accounting; it is determined by the chart of accounts and is reported in the profit and loss statement for the purpose of calculating total costs and subsequently the economic result. Costs are recorded according to the production factor with which their consumption is associated, regardless of the activity within the transformation process in which the consumption occurs. Therefore, this classification is also referred to as the classification of costs by economically homogeneous types, which are directly related to the consumption of individual components of assets or labour. According to this criterion, costs are divided into economically homogeneous groups, as follows (the listed items represent only a concise selection from cost accounts):

- consumed purchases (consumption of materials, energy),
- services (repairs and maintenance, travel expenses, representation costs),
- personnel costs (wage costs, social insurance costs),
- taxes and fees (property tax),
- other costs of economic activity (depreciation of fixed assets, gifts, sold material, write-off of receivables, shortages and damages),
- financial costs (interest expenses, exchange rate losses),
- provisions and allowances for financial costs.

These represent costs arising from the consumption of production factors supplied from outside the enterprise (from suppliers) and are therefore referred to as ***external costs***. The term *primary costs* is also used, as they appear for the first time in the given transformation process, as well as ***simple costs***, since they include only one type of expended production factor.
The importance of the classification of costs by type lies in its ability to determine the structure and level of production factor consumption, to monitor changes in the nature and volume of production, to link the cost plan with other enterprise plans, to serve as the basis for financial and economic analysis, and to provide the foundation for identifying the main directions and factors of cost reduction.

Calculation-Based Classification of Costs
An important prerequisite for effective, i.e., purposeful and goal-oriented, cost management is the allocation of costs to business activities and to the products themselves. This prerequisite is fulfilled by the calculation-based classification of costs, in which the object of cost allocation is the subject of calculation (the computation of costs per unit), also referred to as the cost object. The costs allocated to the subject of calculation are divided, according to the method of allocation, into direct and indirect (overhead) costs. **Direct costs** (cost-independent items) are those costs that can be assigned to the subject of calculation specifically (a clearly defined cost item of a certain volume and price for a particular product) and exclusively, meaning that once the given cost item has been used, it cannot be employed for another product. **Indirect costs** (cost-complex items) are those costs that cannot be assigned specifically and exclusively because there is no identifiable link between the cost and the subject of calculation. Indirect costs per calculation unit are determined by means of a certain allocation.

Calculation-based costs are divided according to the items of the general (standard) calculation formula, which has the following form:

Table 15.1: Cost Sheet

Items of the Calculation Formula	
1.	direct material
2.	direct wages
3.	other direct costs
4.	operating (production) overheads
1.-4.	**Own costs of production (operation)**
5.	administrative overheads
6.	selling overheads
1.-6.	**Own costs of the realised output**
7.	profit (loss)
1.-7.	Selling price of the product

The given calculation formula may be adjusted by enterprises according to their specific conditions and needs by adding, omitting, or renaming certain items and by arranging the costs according to their significance in the creation of the product (performance). The content of the individual items of the general (standard) calculation formula is as follows:

1. **Direct material** – constitutes the essential material component of the production process, e.g., the consumption of raw materials and basic materials of products, semi-finished goods, and services from cooperating enterprises, as well as auxiliary materials, technological fuel, and technological energy.
2. **Direct wages** – are related to the performance of a specific activity, e.g., wages of production workers for time worked or for work completed.
3. **Other direct costs** – do not fall under the previous items of direct costs but can be determined directly for the calculation unit, e.g., technological fuel and energy, or social insurance contributions related to wages.
4. **Production (operating) overheads** – represent the total of costs related to the management and servicing of the production process (or the operation of the enterprise) that cannot be determined directly for the calculation unit. These include, in particular, materials, fuel, energy, transport costs, depreciation, wage costs of managerial and auxiliary production staff, costs for the preparation and testing of new products or technologies, and costs of warranty repairs.
5. **Administrative overheads** – costs associated with the management and administration of the enterprise and with the general servicing of production or non-production activities (possibly including procurement and sales), e.g., office materials, wage costs of administrative employees, and other costs related to administration and management.
6. **Selling costs** – consist of selling overheads and direct selling costs, e.g., costs of packaging, transport, promotion, and advertising associated with specific outputs or their groups.

The calculation-based classification of costs deepens the classification of costs by type according to where and for what purpose the costs were incurred. Depending on specific conditions, certain calculation items may, in some cases, represent direct costs, and in others, indirect costs. The importance of the classification of costs by calculation items lies in the ability to monitor costs according to their purpose and place of origin, to prepare calculations of own costs and selling prices of products, to compare costs across periods or between enterprises, and to identify reserves for their reduction depending on the department and purpose of expenditure.

Classification of Costs in Relation to the Volume of Production

The classification of costs according to the volume of production belongs to the classifications of costs used for managerial accounting and decision-making purposes. A change in the production quantity directly affects the development of total costs, while individual cost items behave differently. When determining a certain optimal production volume, it is necessary to understand the development of costs and to establish the extent to which cost changes depend on changes in production volume. This relationship can be calculated through a ***cost reaction coefficient***, which is used to determine the nature of costs.

It is calculated as follows:

$$C_r = \frac{P_{ChC}}{P_{ChO}} = \frac{\frac{C_1}{C_0} \cdot 100 - 100}{\frac{O_1}{O_0} \cdot 100 - 100}$$

Where: Cr – reaction coefficient,
P_{ChC} – percentage change in costs,
P_{ChO} – percentage change in outputs,
C_0 – costs of the base period,
C_1 – costs of the subsequent period,
O_0 – outputs of the base period,
O_1 – outputs of the subsequent period.

The reaction coefficient expresses the degree of **cost variability** in response to a change in the volume of outputs. The reaction coefficient may be calculated for total costs, in order to determine their overall development, or for individual cost items, whether classified by type, calculation category, or other criteria.

Table 15.2: Classification of Costs in Relation to the Volume of Production

Classification of Costs in Relation to the Volume of Production			Example	Volume of Reaction Coefficient
Variable costs	proportional costs		*basic material*	$C_r = 1$
	non-proportional costs	progressive costs	*overtime allowances*	$C_r > 1$
		degressive costs	*auxiliary material*	$0 < C_r < 1$
		regressive costs	*wages for downtime*	$C_r < 0$
Fixed costs			*depreciation*	$C_r = 0$

Source: Majdúchová & Rybárová, 2019

As follows from the above analysis, from the perspective of the dependence of costs on the volume of outputs, costs are divided into **variable and fixed costs** (Synek et al., 2011). In practice, the clear classification of individual cost types into one or the other group is sometimes difficult and depends on specific conditions.

Variable costs are all types of costs that change when the volume of outputs changes. Based on the direction of development of variable costs in comparison with the volume of production, variable costs are divided into:

1. **Proportional costs** develop in the same proportion as the volume of production. When recalculated per unit of production, they remain constant under unchanged production conditions. From the viewpoint of individual products, they therefore represent constant costs.
2. **Non-proportional costs** develop differently from the volume of production and may be:
   - **Progressive costs** – their total amount increases faster than the volume of outputs and decreases more slowly when the production volume declines. An increasing production volume causes the rise of unit costs. The emergence of progressive costs is usually associated with unplanned activities of the enterprise.
   - **Degressive costs** – change with the volume of outputs, but their total growth is slower than the growth in production volume (and when production volume decreases, they fall faster). An increase in the volume of outputs leads to a reduction in the cost per unit of production.
   - **Regressive costs** – develop inversely in relation to the production volume, i.e., their total amount decreases as the volume of outputs increases and rises when it decreases. These are costs directly associated with the utilisation of the enterprise's production capacity.

Fixed costs represent one of the important reserves for cost reduction. They are sometimes referred to as *capacity costs* because they arise from the need for a global and one-time creation of technical, organisational, and labour conditions (production capacity) to ensure a certain level of production. Their absolute amount changes as a result of changes in the extent of capacities. Within the existing capacity, they do not change at all or only slightly with changes in production volume. The fixed costs per unit of output decrease as production volume increases within a given capacity.

Not all costs that belong to fixed costs behave in the same way when the volume of outputs changes. They may be divided into two groups:

1. **Absolutely fixed costs** – their total amount remains unchanged over the same period, even when the production volume changes. They may be further divided into:
   - one-time costs (e.g., costs associated with the start-up of new production),
   - ongoing costs that depend on time (e.g., salaries).
2. **Relatively fixed costs** – their total amount remains unchanged only within a certain range of production volume. Once the volume of outputs exceeds a certain limit, fixed costs change, not gradually but suddenly – by a jump. These costs predominate within the total amount of fixed costs.

The importance of the classification of costs according to the volume of production lies in identifying fixed costs as a source of efficiency, assessing their utilisation in relation to capacity, supporting decision-making on changes in production volume, and enabling the implementation of break-even or minimum price analysis.

As already stated, the classification of costs according to the volume of production is an important tool of managerial decision-making. With an increase in the enterprise's production

volume (up to a certain limit), the cost per unit of production decreases — this is the so-called ***economies of scale***. This occurs because fixed costs are distributed over a larger number of products.
The share of fixed costs in total costs increases with the growing concentration, mechanisation, and automation of enterprise activities. The **total costs**, considering the classification of costs according to the volume of production, can be calculated as the sum of total fixed costs (FC) and total variable costs (VC). Assuming a proportionate development of variable costs, the **linear cost function** takes the following form:

$$TC = FC + UVC \cdot Q$$

where:

TC	total costs,
FC	fixed costs,
UVC	unit variable costs,
Q	quantity of production.

Break-even Analysis

Fixed costs are characterised by the fact that they exist even in the limiting case when the volume of production is generally zero. Assuming constant prices for a particular type of production and based on the classification of costs into fixed and variable, it is possible to determine the volume of production at which the enterprise achieves neither profit nor loss – the so-called **break-even point**, also referred to as the **critical point** or the **point of inflection**. This represents the volume of production that the enterprise must achieve in order to cover its production costs, while no profit is generated. This volume of production **thus constitutes the lower limit of output, below which the enterprise incurs a loss**.

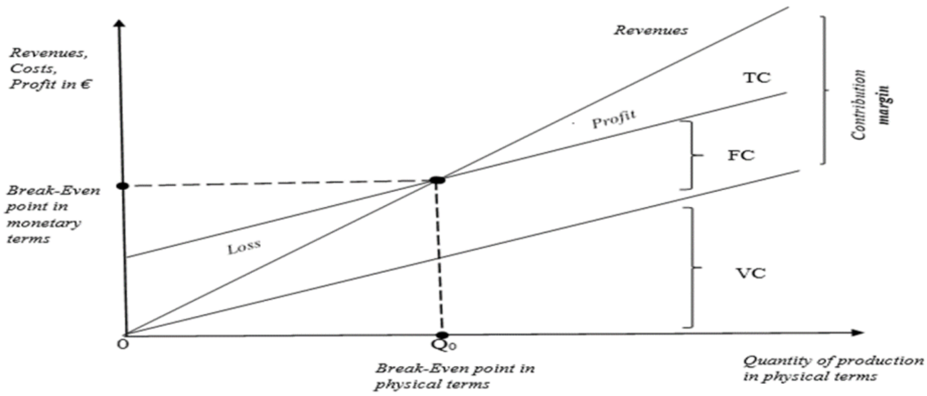


Figure 15.1: Graphical Representation of Break-Even Analysis
Source: Majdúchová & Rybárová, 2019

At a constant price level, revenues develop according to the relationship: $R = USP \cdot Q$

and costs under proportional development: $TC = FC + UVC \cdot Q$

Profit is then calculated as: $P = R - TC$ if $R > TC$

If R = TC, neither profit nor loss arises, that is: $R = TC$

$$USP \cdot Q = FC + UVC \cdot Q$$

After rearrangement: $Q = \frac{FC}{USP - UVC}$

Where:

P - profit

R – total revenues

$USP - UVC$ – unit contribution ***margin,*** i.e., the contribution towards covering fixed costs and profit,

Q – quantity of production (in natural units, e.g., pieces, metres, kilograms, etc.) – **break-even point**,

USP – selling price per unit of production (per piece, metre, kilogram, etc.),

UVC – variable costs per unit of production (per piece, metre, kilogram, etc.),

FC – fixed costs (for the total production volume).

In practice, the contribution margin (the difference between the selling price and variable costs) is often approximated by the **gross spread**, i.e., the difference between the selling price and direct costs. Break-even analysis helps managers determine the minimum volume of profitable production, the utilisation threshold of capacity without incurring a loss, the maximum permissible production costs per product, and the production volume that ensures maximum profit.

CHAPTER 16: SUPPLY AND DEMAND IN PRODUCT AND SERVICE MARKETS

The market mechanism is a process through which prices are determined and resources are allocated in the economy based on interactions between supply and demand. This process is driven by the behaviour of individual market participants, such as producers, consumers, and, in the case of government intervention in the economy, the state, who seek to optimize their decisions in accordance with their goals and constraints. The market mechanism can be described on the basis of two principles:

The principle of optimal behaviour of market participants

This principle focuses on how individual market participants—whether producers or consumers—behave in order to achieve their goals. Every market participant has certain goals that they seek to maximize or minimize. Companies create their optimal production strategies, while consumers develop their optimal consumption strategies.

In an optimal production strategy, producers strive to maximize their profits. This means that they decide how much to produce and at what price to sell in order to achieve the greatest possible profit, taking into account production costs and market prices. Production optimization may involve decisions about the use of resources, technologies, and the choice of production mix.

In an optimal consumption strategy, consumers seek to maximize their utility, which means they decide what goods and services to purchase in order to achieve the greatest satisfaction of their needs and desires, taking into account their budget. Consumption optimization involves choosing between different goods and services that provide them with the most value for their money.

The principle of the trajectory of system development towards equilibrium

The second principle deals with the dynamics of the market mechanism, specifically how the market reaches equilibrium. Market equilibrium occurs when supply and demand are balanced, and there is no pressure to change prices or quantities. The trajectory of the system describes how the market adapts to external changes (such as changes in demand, supply, or prices) and how these changes are reflected in a new equilibrium. This principle is important for understanding how markets respond to various impulses and what mechanisms lead to a return to equilibrium.

Market supply

The supply function is a basic tool in microeconomics that shows the **relationship** between the quantity of goods that firms are willing to offer on the market and various variables that influence this process. The following figure shows the supply curve, which expresses how the quantity of goods supplied depends on the price of these goods. The relationship between price (p) and quantity (q) is positive in this case, which means that as the price increases, firms are motivated to supply more goods to the market.

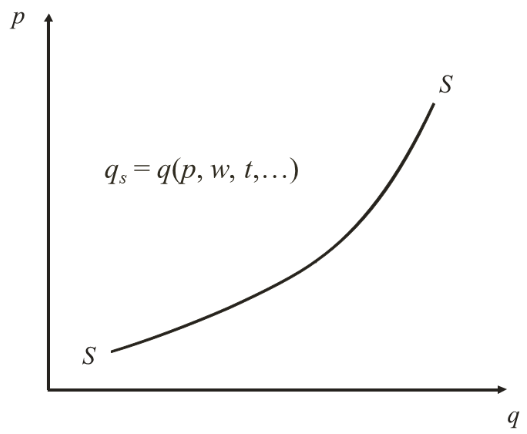


Figure 16.1: Supply Curve

The prices of goods directly influence companies' willingness to produce and offer goods on the market. When the price of goods increases, companies respond by increasing production and supply in order to maximize their profits. This relationship is illustrated as an upward movement along the supply curve. Conversely, when prices fall, companies' motivation to produce declines, leading to a reduction in supply, which is reflected in a downward movement along the curve.

The resulting shape, position, and slope of the supply function depend on all factors other than price that affect the quantity of goods supplied in the market. In the following text, we list some of these factors and how they affect the supply of companies.

Technology: Advances in technology have a significant impact on production productivity. The introduction of new technologies allows companies to produce more at lower costs, which leads to an increase in supply. This effect causes the entire supply curve to shift to the right. For example, the introduction of automation or more efficient production processes can dramatically increase the ability of firms to produce more at lower costs, allowing them to offer more goods on the market at any given price.

Input prices, such as raw materials, labour, and energy, directly affect production costs. If input prices rise, production becomes more expensive, which reduces the willingness of firms to produce the same amount of goods at existing prices. This effect is reflected in a shift of the entire supply curve to the left, which means a reduction in supply at every price. Conversely, if input prices fall, production becomes cheaper, leading to an increase in supply and a shift of the curve to the right.

Supply can also be influenced by government regulations, taxes, subsidies, expectations of future prices, changes in the number of sellers in the market, and even seasonal changes or environmental conditions. These factors can either directly affect production costs or change companies' expectations about future market conditions, which can lead to shifts in the entire supply curve. For example, increasing taxes on certain products can increase production costs and reduce the supply of those products, while subsidies can support production and increase supply.

When looking at the supply curve, it is important to distinguish between movement **along** the curve and a **shift** in the entire supply curve. **Movement along the curve** occurs when there is a change in the price of goods, which causes a change in the quantity supplied in the market, while other factors remain unchanged. This phenomenon is represented by movement along the existing supply curve. For example, if the price of a good rises, the quantity supplied in the market will increase, which will be reflected in an upward movement along the curve. **A shift in the entire supply curve** occurs when a factor other than the price of the good itself changes, causing a change in the total supply in the market. For example, if technology improves, firms will be able to produce more, causing the curve to shift to the right because firms will be able to offer more goods at each price. Conversely, an increase in the cost of raw materials may reduce supply, causing the curve to shift to the left

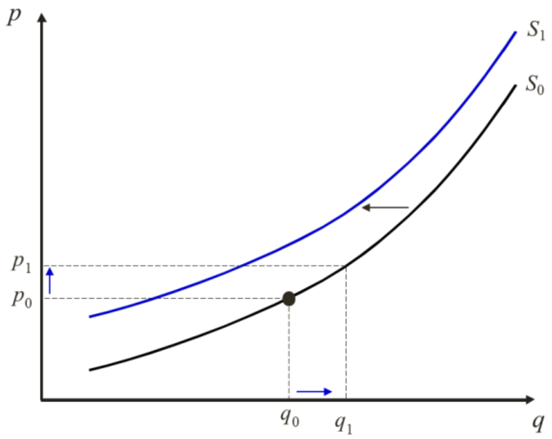


Figure 16.2: The curve shifts

Supply is influenced by several factors that can cause either a change in the quantity supplied at the existing price (a shift along the curve) or a change in the total supply at different prices (a shift of the entire curve). These factors subsequently affect market equilibrium and can lead to adjustments in prices and quantities of traded goods. Understanding these dynamics is key to effective business decision-making and economic policy-making.

Market demand

The demand function shows the **relationship** between the quantity of goods that consumers are willing and able to buy and the various variables that influence this demand. The following figure shows the demand curve, which expresses the negative relationship between price p (on the vertical axis) and quantity q (on the horizontal axis) of the goods demanded. This relationship is governed by the rule: the higher the price of goods, the smaller the quantity consumers are willing to buy, which is reflected in the downward slope of the demand curve.

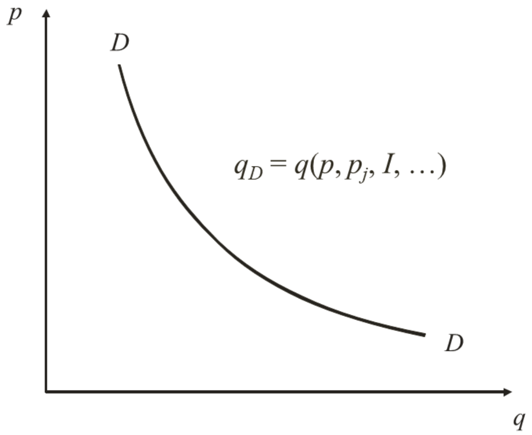


Figure 16.1: Demand curve

As with the supply function, various factors influence the shape and position of the demand function in different ways. Once again, we will list some of the factors that influence the demand function for goods and services.

The price of goods is the main factor influencing demand. If the price of goods rises, consumers respond by reducing the quantity of goods purchased, which is reflected in an upward movement along the curve. Conversely, a fall in price leads to an increase in the quantity purchased, which is reflected in a downward movement along the curve. This relationship is known as the law of diminishing demand, which states that when the price of goods is higher, demand decreases, and when the price is lower, demand increases, assuming ceteris paribus (all other conditions remain unchanged).

Consumer preferences, which include their tastes, fashions, advertising, and other psychological factors, play a significant role in determining the demand for goods and services. A change in preferences can lead consumers to prefer one good over another, causing a shift in the entire demand curve. For example, if advertising increases the popularity of a particular product, demand for that product will increase, causing the demand curve to shift to the right.

Consumer income is another key factor influencing demand. As incomes rise, consumers have more money to spend on goods, which increases demand for goods and services and shifts the demand curve to the right. Conversely, a decline in income causes a decline in demand and shifts the demand curve to the left. However, it is important to note that the impact of income on demand may also depend on the type of goods, as demand for luxury goods may grow more, while demand for basic goods may be less elastic (sensitive) to changes in income.

Other factors that affect demand include the number of consumers in the market, expectations of future prices, prices of related goods (substitutes and complements), government policies, and seasonal changes. For example, if the price of a certain good is expected to rise in the future, consumers may increase their current demand, causing the demand curve to shift to the right. Conversely, a decrease in the number of consumers in the market or an increase in the price of a complementary good may cause demand to fall and the curve to shift to the left.

Even with the demand function, we must distinguish between a shift along the curve and a shift of the entire demand curve. **A shift along the curve** occurs when there is a change in the price of a good, causing a change in the quantity of the good demanded, while other factors remain unchanged. This movement is represented by a change in the point on the existing demand curve. For example, if the price of a good falls, demand for it will rise, and the point will move lower along the curve. **A shift in the entire demand curve** occurs when a factor other than the price of the good itself changes, causing a change in the total demand in the market. For example, an increase in consumer income may cause the demand curve to shift to the right because consumers are willing to buy more goods at any price. Conversely, a decrease in income or a change in preferences may cause the curve to shift to the left, meaning that consumers are willing to buy fewer goods at any given price

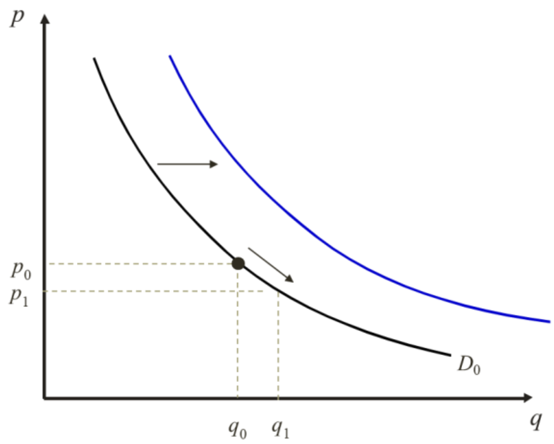


Figure 16. 2: Demand shifts

The demand function helps explain how consumers decide to purchase goods and services based on prices and other factors. Changes in these factors can cause either movement along the existing demand curve or a shift in the entire curve, which in turn affects market equilibrium. Understanding these mechanisms is essential for analysing markets and developing the economy.

Market equilibrium (Equilibrium point)

Market equilibrium represents a state in the market where the demand for a good or service equals its supply. At this point, the quantity that consumers are willing and able to buy exactly matches the quantity that sellers are willing and able to sell. This state of equilibrium is often represented graphically using demand and supply curves, where the demand curve, as already mentioned, shows the quantity of goods that consumers demand at different prices, while the supply curve shows the quantity of goods that sellers are willing to offer at different prices. At the point where these two curves intersect, the equilibrium price and equilibrium quantity are established. In practice, this means that at this price, there is neither a surplus nor a shortage of goods, which guarantees market stability. For example, if we consider the candy market, the equilibrium could be at a price of €4 per kilo and a quantity of 11,000 kilos. At this price and quantity, the quantity of candy demanded is exactly covered by the supply on the market, which "clears" the market and there is no pressure to change the price. Market equilibrium is illustrated in the following figure, where the equilibrium price is p* and the equilibrium quantity is q*. The equilibrium point is located at the point where the demand function and the supply function intersect.

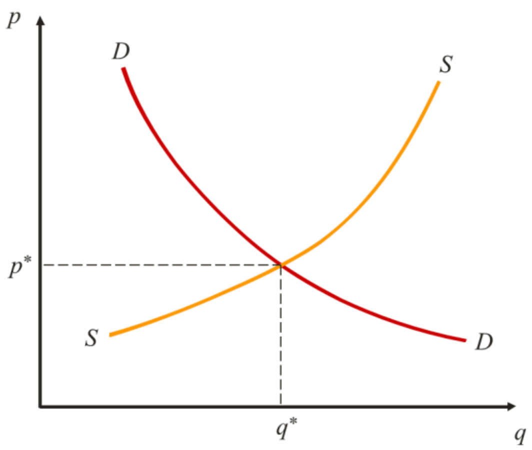


Figure 16.3: Equilibrium

However, this stability only applies if there are no external influences that could affect supply or demand. For example, if income levels, consumer preferences, or production costs remain unchanged, the equilibrium remains unchanged. This concept is key to understanding the basic functioning of markets, as it provides a basis for analysing how markets respond to various changes and shocks.

Surplus and shortage of goods on the market

However, market equilibrium is not always achieved, especially if the price of goods deviates from the equilibrium level. If the price is higher than the equilibrium price, there is a **surplus of goods**. This means that the quantity offered on the market exceeds the quantity that consumers are willing and able to buy. For example, if the price of candy rises to €5 per kilo, companies may be willing to offer 13,000 kilos of candy, but consumers will only be willing to buy 8,000 kilos. This surplus will put downward pressure on prices, as sellers who cannot sell their goods will be willing to lower prices to attract more buyers. The process of price reduction continues until the market returns to an equilibrium price, where supply and demand are once again balanced. This mechanism is automatic and ensures that the market gradually returns to stability

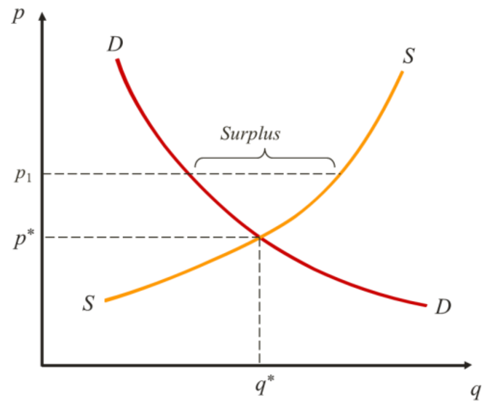


Figure 16.6: Surplus

On the other hand, if the price is lower than the equilibrium price, there will be a **shortage of goods**. In this case, demand for goods exceeds supply. For example, if the price of candy falls to €3 per kilo, consumers will be willing to buy 14,000 kilos, but companies will only be willing to offer 9,000 kilos. This shortage will put pressure on prices to rise, as consumers will compete with each other to obtain a limited quantity of goods and will be willing to pay more. The pressure to raise prices will continue until the price returns to its equilibrium level. This market mechanism ensures that prices are constantly adjusted to balance supply and demand.

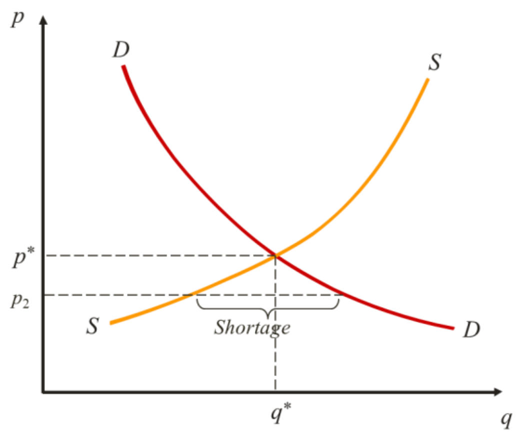


Figure 16.7: Shortage

When analysing equilibrium, it is necessary to mention prohibitive prices and saturated demand. The **prohibitive price of supply** (PPS) is the minimum price at which producers are willing to offer goods or services. Conversely, the **prohibitive price of demand** (PPD) is the maximum price at which consumers are willing to purchase goods or services. Graphically, this is the intersection of the demand function with the y-axis, the price axis. Graphically, this situation is represented by the point at which the supply function intersects the price axis, the y-axis. The last term mentioned was **saturated demand** (SD), which represents the maximum amount of goods or services that consumers are willing to buy. Graphically, this quantity is represented by the point at which the demand function intersects the x-axis, i.e., the quantity of goods.

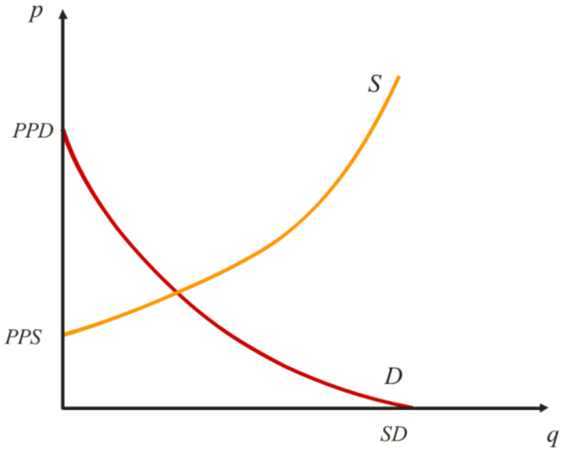


Figure 16.8: Saturated demand

Changes in equilibrium when demand and supply curves shift

However, market equilibrium is not static and may change in response to shifts in the demand and supply curves resulting from changes in various exogenous factors. These factors may include changes in consumer income, technological advances, changes in input prices, changes in consumer preferences, or even government policies.

A change in the demand curve occurs when there is a change in one or more factors that affect demand, other than the price of the good itself. For example, if consumer income increases, demand for goods increases because consumers have more money to purchase goods. This increase in demand causes the demand curve to shift to the right, leading to an increase in both the equilibrium price and quantity. Returning to the example of the candy market, increased demand could raise the price to €5/kg, and the quantity traded in the market would increase to 12,000 kg.

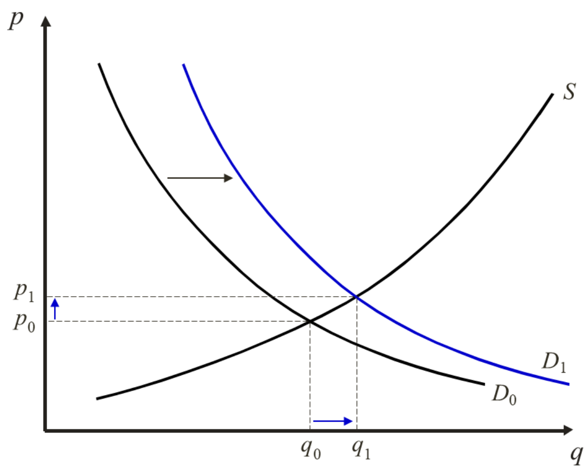


Figure 16.4: Changes in equilibrium

A shift in the supply curve occurs when one or more factors affecting supply change, such as input prices, technological innovations, or regulations. For example, if technological advances improve production efficiency, firms will be able to produce more at the same cost, shifting the supply curve to the right. The result will be a decrease in the equilibrium price and an increase in the equilibrium quantity. On the other hand, if input prices, such as raw material costs or wages, increase, the supply curve will shift to the left, causing an increase in the equilibrium price and a decrease in quantity.

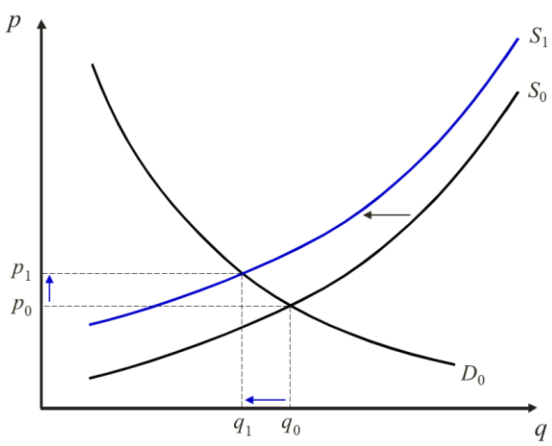


Figure 16.5: Shift in the supply curve

In practice, it often happens that the demand and supply curves change simultaneously, leading to changes in the equilibrium price and quantity. Let's imagine a situation where, on the one hand, consumer incomes have increased, causing the demand curve to shift to the right (increased demand for goods). On the other hand, however, there has been an increase in production costs – for example, an increase in the price of sugar, which has caused the supply curve to shift to the left (reduced supply of goods).

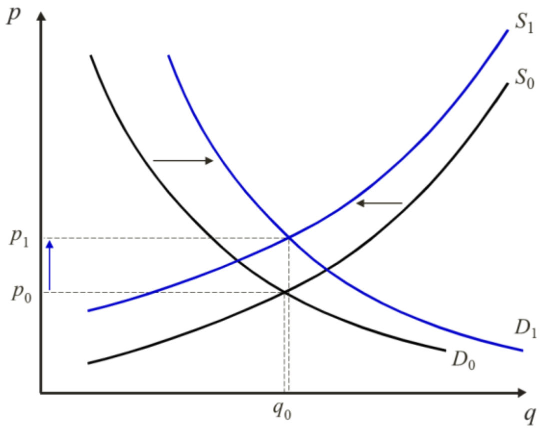


Figure 16.6: Simultaneous changes

In this case, the resulting effect is an increase in the equilibrium price, because increased demand for goods meets a limited supply. However, the effect on quantity depends on the relative strength of these two shifts. If the shift in demand is greater than the shift in supply, quantity may increase. However, if the shift in supply is greater, quantity may decrease. In some cases, quantity may not change if the shifts are balanced.

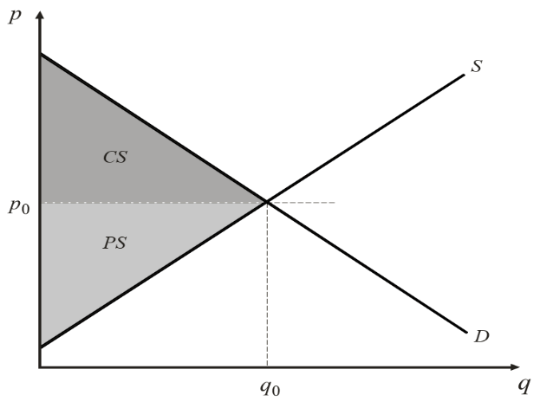


Figure 16.7: Consumer vs. Producer surplus

Consumer surplus CS is the difference between what a consumer is willing to pay for a good and what he must pay for it. Consumer surplus will be the area under an ordinary demand curve and above the price of the good. Changes in consumer surplus can measure how much better off or worse off a consumer is if the price changes.

Producer surplus, PS, is the difference between the amount that a firm *actually receives* from selling a good in the marketplace and the minimum amount the firm *must receive* in order to be willing to supply the good in the marketplace. Just as consumer surplus provides a measure of the net benefit enjoyed by price-taking consumers, producer surplus provides a measure of the net benefit enjoyed by price-taking firms from supplying a product at a given market price. **Net Economic Benefit** on perfect competitive market is the sum of consumer surplus and producer surplus.

CHAPTER 17: MANAGEMENT AND MANAGER

The concept of management

Management is essential in any organisation, regardless of whether it is a large corporation, a small start-up, a hospital, an office, a school, or a non-profit organization. It is a complex set of activities carried out by an individual or team in order to achieve the vision, goals and fulfil the mission. The success of the organization depends on the quality of these management employees and their ability to use resources efficiently and to set up all activities in the organisation.

Management can be defined as *"a comprehensive set of activities through which a managing entity purposefully influences a managed entity in order to achieve the highest possible value for owners, employees, and customers."*

The main goal of management is to effectively direct activities and resources—financial, material, technological, and human—in order to achieve desired objectives. The basic management functions, such as **planning, organizing, human resource management, leading, and controlling,** are performed by every manager in all types of organizations. These functions are applied universally, across countries, corporate cultures, industries, and managerial personalities.

The success of an organization depends on the way it is managed. **Good management** enables organizations to achieve their goals and desired outcomes.

- **Planning** helps define objectives and sets a clear direction.
- **Organizing** work and people enables efficient use of resources and establishes structure in operations.
- Through **human resource management**, managers acquire qualified personnel and optimize individual workloads.
- **Leading** provides clear vision and direction while facilitating communication within the organization.
- **Controlling** compares goals with actual results and identifies existing and potential future problems.

The individual functions and levels of management

The functions of management represent the activities that form the very content of the management process itself. The basic management functions include **planning, organizing, human resource management, leading, and controlling**. This classification of management functions reflects the chronological sequence of setting up and running processes within an organization.

Planning is the first function in management theory. Planning serves as a managerial tool that enables the organization to cope with environmental complexity. An organization that plans is capable of analysing its environment, forecasting future developments, setting realistic goals, and choosing appropriate methods to achieve them while respecting the constraints of the business environment. While **strategic planning** focuses on defining the organization's long-term direction, **operational planning** specifies concrete steps for day-to-day activities, taking strategic objectives into account.

Organizing builds upon planning and serves as the basic mechanism for activating plans. It creates and maintains relationships among all organizational resources by defining which resources are to be used for specific activities, and when, where, and how they should be used. Thorough organization helps minimize costly weaknesses such as duplication of effort and underutilized resources. The purpose of organizing is to create conditions for coordination of effort through the establishment of process structures and relationships among tasks, authority, and responsibility. The role of organizing is to reduce uncertainty and ambiguity in the behaviour of people within the organization, and to increase the likelihood that members will act purposefully toward common goals.

Human resource management refers to activities focused on employees and encompasses all aspects related to people in the work process. It represents a comprehensive and systematic approach to employing and developing individuals with the goal of increasing organizational efficiency in accordance with ethical values. There are no universal formulas for successful human resource management. It is rather a set of policies, principles, and procedures—often referred to as **best practices**—that lead to effective outcomes. A key prerequisite for success in managing people is recognizing their importance and value to the organization, as well as understanding the complexity of the social and economic processes that strongly influence human resource management.

Leading is defined as the process of influencing people in such a way that their activities contribute to the achievement of group and organizational goals. "Effective leadership is a crucial prerequisite for the realization of all other managerial functions. The essence of sound leadership lies in the manager's ability to motivate and communicate with people so that everyone knows what to do and how to do it."

Controlling represents a continuous process of setting standards, measuring performance, comparing actual performance with the established standards, and taking corrective managerial actions to ensure the effective and efficient course of activities within the organization. Control is a continuous and dynamic process. Managers must repeat it constantly in an ongoing cycle. Therefore, control is not a one-time activity or a final result; it continues over time and requires daily, weekly, and monthly attention from managers to ensure that performance levels meet the established standards.

The role of the manager in a company

Organizations can be managed **vertically**, **horizontally**, or through a **combination of both approaches**. In a **vertical structure**, decisions are made from the top down. A **horizontal structure** is a decentralized form of management in which employees are involved in decision-making, and decisions are made at various levels depending on the specific project.

From the perspective of vertical division, most organizations have **three levels of management** — top, middle, and lower management. These managers are classified according to their hierarchical authority and are responsible for different tasks.

Top Management

The main task of top management is to view the organization as a whole, define its vision and mission, and create the main strategic plans. Top management usually consists of specialists in the field. It typically includes the organization's directors responsible for specific departments — Chief Operating Officer (COO), Chief Marketing Officer (CMO), Chief Information or Technology Officer (CIO or CTO), Chief Financial Officer (CFO), and Chief Executive Officer (CEO), as well as members of the board of directors, the chairperson, president, vice president, general manager, and others. Top management influences the functioning of the entire organization and is responsible for overall results. In addition to professional expertise, top managers are expected to demonstrate **decision-making ability, stress management, risk-taking, and effective and clear communication.**

Middle Management

Middle management is subordinate to higher management, to which it reports. Since middle managers are involved in the day-to-day operations of the company, they can provide valuable information to top management to help improve organizational performance. Examples include branch managers, department heads, regional directors, and division managers. Their role is to monitor goal achievement within their departments, communicate with their teams, and inform top management about the current status of their department. Middle management proposes and implements solutions, diagnoses problems, and coordinates processes and tasks across the managerial structure. The quality of middle managers largely depends on their **communication and interpersonal skills.**

Lower Management

Lower managers are **first-line managers**, sometimes referred to as **team leaders**. They are often highly skilled professionals and specialists. Their focus is on supervising and managing specific employees and processes. They must possess strong technical knowledge to be able to check and evaluate the work performed by their staff.

For example, an accounting manager must be able to perform accounting tasks and understand the specific functions of each employee in the department to fill potential gaps. Similarly, a first-line manager in an automobile manufacturing plant should know how to operate most machines and assess the productivity of different positions—ideally based on personal experience.

At the same time, lower managers must possess **soft skills** and be excellent communicators to build professional relationships in the workplace. They must observe and actively listen, give and receive feedback, and effectively align processes and resources within their area of responsibility.

Horizontal management emerged as a response to the need for **greater coordination among different corporate departments (department of production, finance, HR, marketing, sales) and organizational activities.**

The **nuclear industry** is unlike most other industries because of its **extremely high safety, security, and regulatory requirements**. These characteristics shape how organizations are managed — especially when it comes to **centralization, control, and decision-making**.

Managerial roles

According to Mintzberg's typology, managerial roles fall into three basic categories: interpersonal, informational, and decisional roles.

Interpersonal roles. This category includes the roles which concern interactions with people working inside and outside the organization. Basically, the majority of managers' time is spent on interpersonal communication through which things get done. The managerial roles in this category are figurehead, leader, and liaison.

Figurehead: The manager performs ceremonial and symbolic duties, such as representing the organization at official events, signing documents, or greeting visitors. *Example:* Attending a ribbon-cutting ceremony or hosting a delegation.

Leader. The manager motivates, guides, and develops employees; responsible for staffing, training, and performance. *Example:* Providing feedback, coaching, or conducting performance appraisals.

Liaison: The manager builds and maintains networks of contacts inside and outside the organization to exchange information and resources. *Example:* Meeting with partners, suppliers, or other department heads.

Informational roles. The informational category involves creating, receiving, or sharing information with coworkers. The manager collects information from sources both inside and outside the organization, processes it, and delivers it to those who need it. The managerial roles in this category are monitor, disseminator, and spokesperson.

Monitor: The manager gathers and scans information from the environment to stay informed about organizational and market trends. *Example:* Reading industry reports, tracking competitors, or monitoring internal performance data.

Disseminator: The manager shares relevant information with subordinates or team members to keep them informed. *Example:* Forwarding reports, summarizing new policies, or explaining company goals.

Spokesperson: The manager communicates on behalf of the organization to external stakeholders. *Example:* Giving presentations, media interviews, or reports to higher management.

Decisional roles. Interpersonal roles are about dealing with people, and informational ones are about dealing with knowledge. Decisional roles are about action. By communicating with people and using information, managers make decisions that lead the organization to its goals. The managerial roles in this category are entrepreneur, disturbance-handler, resource-allocator, and negotiator. These roles involve making and implementing decisions that affect the organization.

Entrepreneur: The manager initiates change, innovation, and improvement projects to enhance performance. *Example:* Launching a new service or improving internal processes.

Disturbance Handler: The manager deals with conflicts, crises, or unexpected problems. *Example:* Resolving team disputes or responding to emergencies.

Resource Allocator: The manager decides how to distribute resources (money, time, personnel) across projects or departments. *Example:* Approving budgets or assigning tasks.

Negotiator: The manager represents the organization in important negotiations, both internally and externally. *Example:* Negotiating contracts, salaries, or project deadlines.

A **manager in the nuclear industry** is not just a leader; he is also a **guardian of safety, compliance, and ethical responsibility.** Their success is measured not by production output, but by **safety, reliability, and public trust.**

Examples of manager activities in the nuclear industry:

- A plant manager must ensure that maintenance tasks on the reactor cooling system meet every safety standard before restarting operations.
- A project manager deciding on reactor modernization must evaluate both the technical feasibility and long-term strategic value.
- A shift supervisor ensures that operators are well-rested, certified, and briefed before taking over control room duties

Differences in management from a territorial perspective.

Management practices around the world are influenced by cultural values, historical development, and institutional environments. National culture affects how organizations define leadership, make decisions, motivate employees, and resolve conflicts. Below is a comparison of major management traditions across key regions.

American management style:

- **Individualism and competition:** Strongly influenced by the cultural emphasis on personal achievement and self-reliance.
- **Result-oriented:** Success is measured by performance, productivity, and measurable outcomes.
- **Decentralized decision-making:** Managers delegate authority and expect initiative from subordinates.
- **Short-term focus:** Quarterly results and shareholder value often dominate long-term sustainability concerns.
- **Strong performance management:** Reward systems (bonuses, promotions) are closely tied to individual performance.

Communication and Leadership

- **Direct and explicit communication** – clear feedback and assertive dialogue are valued.
- **Leadership style:** Often **transactional or transformational**, focusing on motivation, goal setting, and accountability.
- **Work culture:** Encourages innovation and risk-taking; failure is often seen as a learning opportunity.

Strengths and Weaknesses

✅ Fast decision-making, innovation, and adaptability.

❌ Can neglect employee well-being, work-life balance, and long-term relationships.

Japanese Management Style:

- **Collectivism and harmony:** The group's well-being and consensus are more important than individual recognition.
- **Lifetime employment tradition:** Although changing, many Japanese companies still value long-term loyalty and job security.
- **Bottom-up decision-making (ringi system):** Decisions are discussed and approved gradually through consensus rather than imposed from the top.
- **Continuous improvement (Kaizen):** Emphasis on incremental innovation, quality control, and process optimization.
- **Long-term orientation:** Strategic patience and focus on sustainable growth.

Communication and Leadership

- **Indirect and context-sensitive communication (high-context culture):** Politeness, subtlety, and reading between the lines are key.
- **Leadership style: Participative and paternalistic** – leaders act as mentors or "organizational fathers."
- **Work culture:** Teamwork, loyalty, and conformity are highly valued.

Strengths and Weaknesses

✅ Strong teamwork, quality standards, and long-term vision.

❌ Slow decision-making and resistance to radical change.

German Management Style:

- **Structured and systematic approach:** Strong emphasis on rules, procedures, and technical expertise.
- **Precision and planning:** Germans value detailed preparation, accuracy, and long-term strategic thinking.
- **Hierarchical but participative:** While hierarchies are clear, decisions often involve consultation with experts.
- **Strong worker representation:** Works councils and unions play an important role in corporate decisions.

Leadership and Communication

- **Leadership:** Rational, fact-based, and professional. Leaders are expected to be technical experts, not charismatic figures.
- **Communication:** Formal, direct, and focused on facts rather than emotions.

Strengths and Weaknesses

✅ Reliability, efficiency, and quality orientation.

❌ Slow decision-making due to extensive consultation and bureaucracy.

Central and Eastern European (CEE) Management Style

- **Transitional nature:** Evolved from centrally planned economies to market systems in the 1990s.
- **Hybrid model:** Combines Western managerial methods with remnants of hierarchical, authority-based traditions.
- **Developing corporate culture:** Growing emphasis on innovation, HR development, and modern leadership practices.
- **Pragmatic approach:** Managers often adapt flexibly to changing environments and limited resources.
- **Leadership and Communication**
- **Leadership:** Still somewhat hierarchical; leaders are expected to provide direction and maintain control.
- **Communication:** More formal than in Western Europe, but increasingly open and participative in younger organizations.
- **Generational divide:** Younger managers tend to favour teamwork, openness, and empowerment.

Strengths and Weaknesses

✅ Flexibility, adaptability, and growing professionalism.

❌ Inconsistent leadership quality, limited trust, and slower cultural transformation in some organizations.

CHAPTER 18: PLANNING AND ORGANIZING

The essence of planning, basic types of plans

Planning is the first function in management theory. There is no point in performing other functions unless the organization has a clearly defined goal—unless it knows where it wants to go and how it intends to get there. An unplanned, or in other words, improvised approach is inherently inefficient. This means that if an organization has no set objective, no activity can bring it closer to a goal that does not exist.

Planning is a management tool that enables an organization to deal with the complexity of its environment. An organization that engages in planning is capable of analysing its surroundings, forecasting future developments, setting realistic goals, and choosing the path to achieve them while respecting the constraints associated with the business environment.

While **strategic planning** focuses on defining the organization's fundamental direction, **operational planning** specifies the steps required for day-to-day activities, naturally taking strategic goals into account.

In general terms, the **planning process** within an organization encompasses all planning activities across all hierarchical levels. The key activities of the planning process include:

1. **Goal setting**, which describes the desired future state;
2. **Defining the path** to achieve this goal; and
3. **Identifying the resources** that will be used to reach these objectives.

Planning can be distinguished according to various criteria. **Based on hierarchical level**, planning can be divided into **strategic** and **operational planning.**

Strategic Planning

- Strategic planning is performed at the **top management level** and focuses on the **long-term direction and overall goals** of the organization.
- Its purpose is to define the organization's **mission, vision, and strategic objectives**, providing a roadmap for achieving competitive advantage and sustainable growth.
- Strategic planning involves analysing the internal and external environment, identifying opportunities and threats, and setting priorities for resource allocation.
- Tools commonly used include **SWOT analysis, PESTLE analysis, the BCG matrix, the Ansoff matrix, and business model frameworks**.

Operational (Tactical) Planning

- Operational planning is carried out at the **middle and lower management levels** and translates strategic objectives into **specific, actionable tasks**.
- It focuses on the **short- and medium-term execution** of strategies through detailed plans, schedules, and resource allocation.
- Operational planning ensures that daily activities and departmental goals are aligned with the organization's strategic direction.
- Examples include production schedules, staffing plans, budget allocation, and sales targets.

Based on the time horizon, planning can be **long-term, medium-term, or short-term.**

Long-Term Planning

- Typically covers **three to five years or more**, depending on the industry and organization.
- Long-term planning focuses on strategic goals, investment decisions, capacity expansion, and major organizational changes.
- It requires forecasting future trends, market developments, and technological advancements.

Medium-Term Planning

- Usually covers a period of **one to three years**.
- Medium-term planning bridges the gap between strategic goals and short-term operations.
- It involves creating plans for specific departments, projects, or initiatives that support long-term objectives.
- Examples include workforce development plans, multi-year marketing campaigns, or phased implementation of new technologies.

Short-Term Planning

- Covers a **few months up to one year** and is often very detailed.
- Short-term planning is concerned with day-to-day operations and immediate objectives, ensuring that resources are used efficiently.
- It includes budgeting, scheduling, inventory management, and sales forecasting.
- Short-term plans are usually flexible to respond quickly to unexpected changes in the environment or internal conditions.

Based on the planning area, we can distinguish **procurement plans, inventory plans, production plans, sales plans, financial plans, cost plans, profit plans, human resource plans**, and so on.

Based on the availability of information, planning can be classified as **planning under certainty** (with complete information) or **planning under uncertainty** (with incomplete information).

Plans within an organization form an **interconnected system**, in which individual plans influence one another. **Integration of plans** can take a hierarchical form, where lower-level plans are derived from higher-level plans. An example of this is an operational plan, which must be developed so that its objectives and activities align with the strategic plan and the direction established for the organization.

Similarly, planning often follows a **sequential logic**, where information and results from previous plans are reflected in subsequent plans. For instance, in a **sales plan**, the organization determines market size and estimates how many products it can sell. This is followed by the **production plan**, in which the company plans how many products to manufacture, taking into account the sales forecast. Once production quantities are planned, the organization determines the required **material inventory** to support this production. Next, the organization evaluates whether **additional investments** are needed, for example, due to capacity, technology, or other factors. Finally, all these plans must be translated into a **financial plan**, where assumptions and forecasts are expressed in monetary terms.

Overview of Methods by Type of Plan

Table 18.1: Methods by Type of Plan

Plan	Methods, Techniques, and Concepts
Strategic Plan	PIMS, SWOT, Business Model Canvas, Lean Canvas, PESTLE, Brainstorming, Delphi Method, Scenarios, BCG Matrix, Ansoff Matrix, Value Chain
Marketing Plan	Time Series Extrapolation, Regression Analysis, 4P (Product, Price, Place, Promotion), Product Market Potential, Sales Forecast of a New Product Relative to its Predecessor, Contribution Margin (%)
Production Plan	ABC Method, Make-or-Buy Analysis, Contribution Margin, Capacity Balancing, Optimal Order Quantity, Aggregate Planning, CPM, PERT, Gantt Chart
Human Resource Plan	Workforce Balance, Standard Hours Method, Service Standards Method, Number of Workstations Method, Time-Saving Method, Index Method

Investment Project Plan	Payback Period, Net Present Value (NPV), Internal Rate of Return (IRR), Price-Earnings Ratio, Profitability, Annuity Method
Financial Plan	Balance Sheet, Working Capital Requirement, Break-Even Point, Direct and Indirect Cash Flow Methods, Financial Ratios Method, Percentage-of-Sales Method, Break-Even Analysis

Planning in the **nuclear energy sector** has several **specific characteristics** that distinguish it from planning in other industries, mainly because of **safety, regulatory, and technological complexity. P**lanning in nuclear energetics is typically **long-term**, often spanning **20–60 years**, reflecting the life cycle of nuclear power plants — from design and construction to operation, decommissioning, and waste management. Also very stage of planning must comply with **national and international nuclear safety regulations.**

Construction and production planning in the power and nuclear industries is associated with long-term planning. Most nuclear power plants have been designed for 30 to 40 years of operation. This horizon applies mainly to second-generation reactors. Abroad, the standard of planning for production and daily operation is longer (in the USA, the Nuclear Regulatory Commission normally allows operation for up to 60 years; some units have already been licensed for up to 80 years). Jaslovské Bohunice V2 units (VVER-440/V-213) - design life of 30 years (until 2015-2020) was extended to 60 years after upgrades and investments. Similarly, Mochovce 1 and 2 have been upgraded for long-term operation.

Organizing, organizational structures

The purpose of **organizing** is to create conditions for coordinating efforts by establishing a structure of processes and a structure of relationships among tasks, authority, and responsibilities. The role of organizing is to reduce uncertainty and ambiguity in the behaviour of people within the organization, or in other words, to increase the likelihood that organizational members will act purposefully toward the organization's goals.

As one of the core management functions, organizing builds upon planning and serves as the primary mechanism for implementing plans. It establishes and maintains relationships among all organizational resources by defining which resources are to be used for specific activities, and **when, where, and how** they should be utilized. Thorough organizing helps to **minimize costly inefficiencies**, such as duplicated effort or underutilized organizational resources, ensuring that the organization's activities are carried out efficiently and effectively.

Organizations can be viewed as **open systems** that, in order to survive, must necessarily **interact with their environment** and continuously **adapt** to it. In a broad sense, the **business environment** is infinite and includes everything outside the organization. From a management perspective, however, it is crucial to focus on those **external factors** to which the organization is sensitive and to which it must necessarily respond in order to survive. There are **ten key**

areas of the external environment that are important to analyse, divided into **two main groups**:

Factors with Direct Contact and Impact

These are factors with which the organization interacts directly and which have an immediate effect on its ability to achieve goals. They include:

1. **Industry** – Within the industry in which the company operates, it is important to monitor the development of competitors, the size and competitiveness of the entire sector, and related industries.
2. **Raw Materials** – The organization must analyse relationships with suppliers of raw materials used in production, as well as the real estate market if the organization owns or leases property.
3. **Market Factor** – This refers to **customer behaviour**, identifying current and potential future clients. Changes in consumer behaviour and opportunities to acquire new customers are particularly important.
4. **Human Resources Factor** – This includes the labour market, employment agencies, universities, vocational schools, employees in other organizations, and labour unions. These are all partners that help the organization secure its most important resource: **human capital**. The **fourth industrial revolution** has created enormous pressure for new knowledge and skills among employees, which are rapidly evolving, making **lifelong learning** essential.
5. **International Environment** – This includes the entry of foreign companies into the domestic market, opportunities for the organization to enter foreign markets, and developments in exchange rates, all of which affect business operations.

Factors with Indirect Impact

These areas do not directly affect day-to-day operations but influence the organization indirectly and can potentially impact all businesses:

6. **Financial Environment** – Developments in stock markets, banking sector services such as business loans, and private investors.
7. **Technology** – Changes in production technology, support for science and research, information technology, and e-commerce.
8. **Economic Conditions** – Economic cycles, unemployment rates, inflation.
9. **Government** – Legislative environment, tax and contribution systems, judiciary, political situation in the country, and local governance.
10. **Socio-Cultural Environment** – Average age of the population, demographic indicators, values, beliefs, education, religion, work ethic, consumer and environmental movements.

Additional Factor

11. **Environment and Sustainability** – Many organizations today adhere to the principles of **corporate social responsibility**, which include environmentally conscious business practices. This involves ecological management throughout the production process, from material selection and transportation to waste recyclability. **Eco-innovations** are increasingly sought in innovation processes. It is also important to consider the tightening of legislation regulating the environmental impacts of business activities, which organizations must comply with.

A business is a **socio-economic system** composed of two subsystems: the **managing subsystem** and the **managed subsystem**. Together, these form an **organic unity**. In management terminology, when we refer to an **organizational structure**, we mean the structure of the organization's management system. The organizational structure represents a set of **elements** (units, workstations, departments, or divisions) and the **relationships between them:**

Formalization refers to the amount of **written documentation** within an organization. It includes rules, regulations, procedures, and other documents that organizations create to support and coordinate complex and diverse tasks by regulating behaviour. The greater the number of tools used to guide activities, and the more definitions, descriptions, and internal procedures an organization employs, the higher the level of formalization. Conversely, low formalization reflects management's trust in employees, relying on their knowledge, skills, and judgment rather than on extensive documentation. Formalization is determined not only by the existence of rules but also by the degree to which employees comply with them. In practice, it is common for organizations to have established internal guidelines that are not followed or are ignored by employees. Examples include employee handbooks, job descriptions, and standard operating procedures that guide daily tasks. Reporting systems and performance evaluation criteria also reflect formalization. The more these rules are documented and followed, the higher the level of formalization in the organization.

Specialization refers to the extent to which organizational tasks are divided into distinct job positions. **Job specialization**, also known as the **division of labour**, allows managers to take complex tasks and break them down into smaller, more precise tasks that individual employees can complete. Each employee is trained specifically on how to perform one small, specialized task in the most efficient way. Over time, the employee becomes highly skilled and proficient in performing that task. This approach enables each member of the organization to become, to a certain degree, an expert in the activity they perform.

Centralization refers to the hierarchical level that holds **decision-making authority**. When decision-making occurs at the highest level, the organization is centralized. When decisions are delegated to lower levels of the organization, it is decentralized. Examples of organizational decisions that can be centralized or decentralized include: the purchase of equipment, goal setting, supplier selection, pricing, employee hiring, and decisions regarding marketing territories.

The term **hierarchy** was first used in the sense of an organized arrangement of people or things around the 17th century. Hierarchy represents a specific way of organizing elements within an organization's structure, embodied by employees, groups, or individual units, where each element can be connected to at most one superior and several subordinates. A characteristic feature of hierarchy is the **relationship of authority and subordination**, which is evident not only in organizational structures but also in other social systems, such as the military or religious institutions. In a business context, hierarchy is closely related to the concept of **span of management**. The span of management (or span of control) is defined as the number of employees who report directly to a single manager.

Types of organizational structures

1. Organizational structures based on the exercise of decision-making authority:

- **Line organizational structure**
- **Line-and-staff organizational structure**

2. Organizational structures based on the principles of departmentalization, i.e., the way activities, people, and resources are grouped:

- **Functional organizational structure**
- **Divisional organizational structure**, which can be based on:
    - Products
    - Customers
    - Geography (territory)
- **Matrix structure**

Line Organizational Structure: Decision-making authority flows **directly from top management to lower levels** in a clear, vertical chain of command. It is simple and easy to understand, but can be rigid and slow in handling complex tasks. **Example:** A small manufacturing company where the CEO directly supervises production, sales, and finance managers.

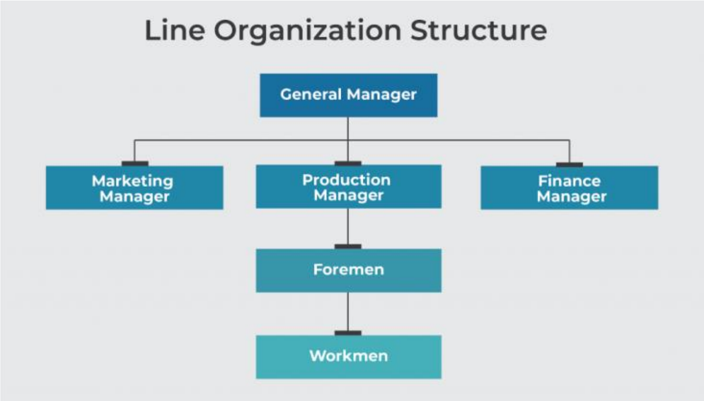


Figure 18.1: Line Organization Structure

Line-and-Staff Organizational Structure: Combines the **direct authority of line managers** with the **advisory roles of staff specialists** who support decision-making. Allows expert guidance without disrupting the chain of command. **Example:** A hospital where doctors and nurses report to a chief medical officer (line), while HR, legal, and IT provide advice and support (staff).

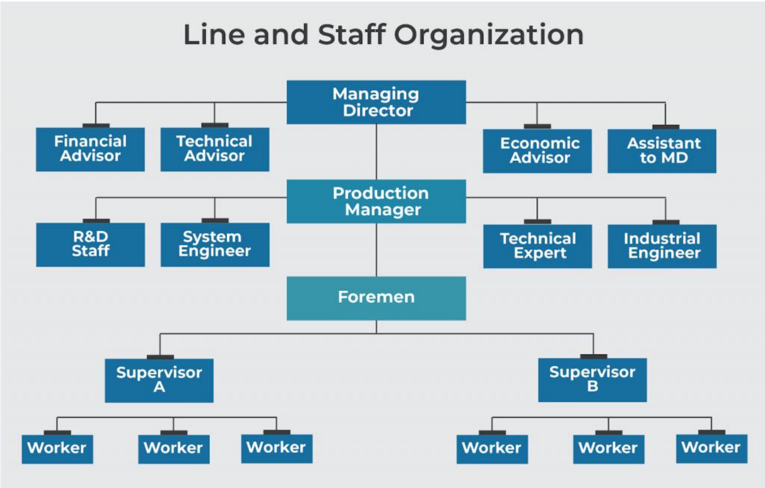


Figure 18.2: Line and Staff Organization

Functional Organizational Structure: Groups employees based on **specialized functions** such as marketing, finance, production, or R&D. Promotes efficiency within departments but may create silos and limit communication across functions. **Example:** A multinational corporation like Procter & Gamble with separate departments for marketing, product development, and finance.

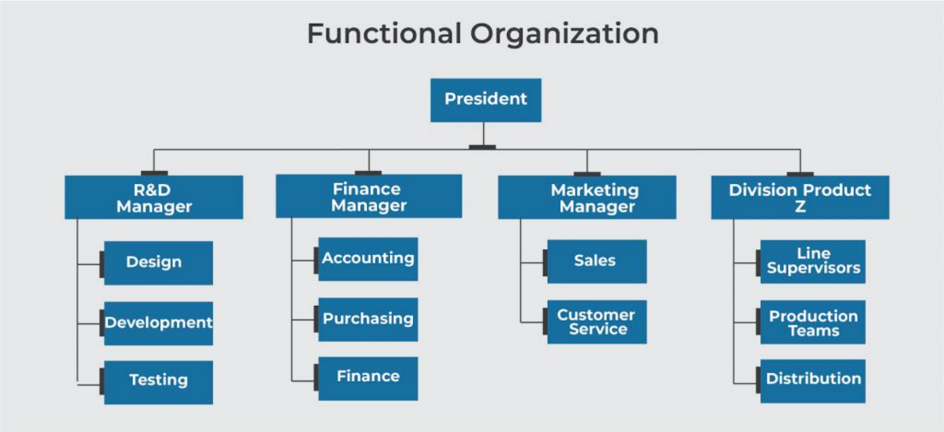


Figure 18.3: Functional Organization

Divisional Organizational Structure: Groups activities around **products, customers, or geographic regions**. Each division operates as a semi-autonomous unit.

- **Product-based:** Each product line has its own production, marketing, and sales teams. *(Example: Apple with divisions for iPhone, Mac, and iPad)*
- **Customer-based:** Units are organized by customer type or market segment. *(Example: A bank with separate divisions for retail, corporate, and private banking)*
- **Geography-based:** Units are organized by region or country. *(Example: Coca-Cola with divisions for North America, Europe, and Asia-Pacific)*

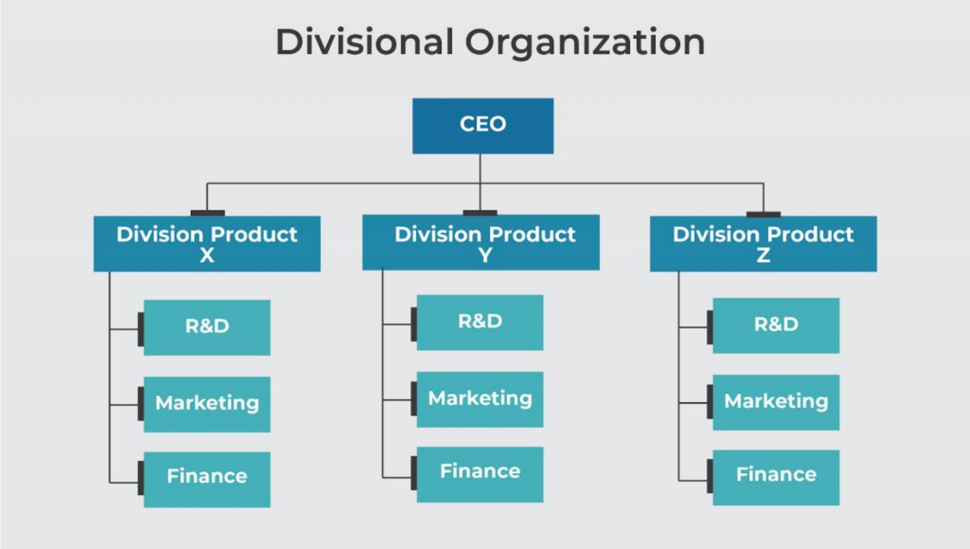


Figure 18.4: Divisional Organization

Matrix Structure: Combines **functional and divisional structures**, where employees report to **both a functional manager and a project or product manager**. Promotes flexibility and collaboration, but can lead to confusion in reporting relationships. **Example:** A consulting firm like Deloitte, where consultant's report to both a practice leader (functional) and a client project manager (project-based).

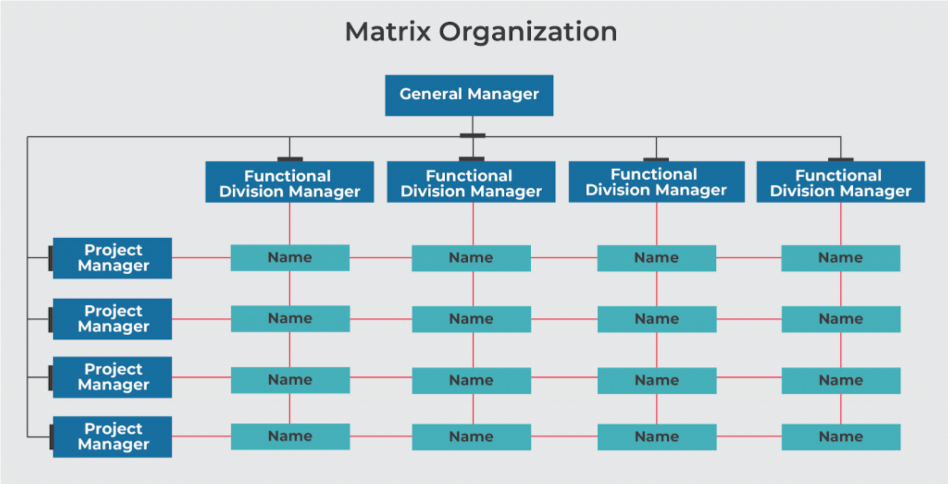


Figure 18.5: Matrix Organization

Source of the images of organizational structures: https://www.learnovita.com/what-are-the-types-of-organization-in-pmp-articles

CHAPTER 19: CONTROL AND CONTROL MECHANISMS

Control is a **managerial function** that involves **monitoring activities, comparing actual performance with planned objectives,** and **taking corrective action** to ensure that organizational goals are achieved effectively and efficiently. C**ontrol means checking whether things are going as planned — and correcting them if they are not.**

It helps managers ensure that:

- People and processes stay on track,
- Resources are used properly, and
- The organization moves toward its strategic goals.

Examples of control in Energetics and Nuclear Management

- Monitoring reactor performance to ensure it operates within safety limits.
- Comparing energy output with the planned production schedule.
- Taking corrective action if temperature, pressure, or radiation levels deviate from the set standards.

Control can have many positive meanings, including the pursuit of order, predictability, or reliability. When things are under control, for example, suppliers know what to deliver and when, people know what they are expected to do, customers know when they can expect goods to be delivered, and employees know they will be paid for their work.

Effective control in management is based on several fundamental principles that ensure organizational activities stay aligned with goals. The **principle of alignment with objectives** emphasizes that control must directly support the achievement of the organization's main aims — for instance, in a nuclear power plant, all control systems are focused on maintaining safety and reliability rather than only maximizing output. The **principle of prevention** highlights that control should be forward-looking, detecting possible problems before they occur, such as using predictive maintenance to identify wear in cooling pumps. The **principle of standards** requires clearly defined performance benchmarks, like specifying acceptable temperature or pressure ranges in reactor operation. The **principle of measurement** ensures that performance can be evaluated through quantitative or qualitative data, for example, measuring energy production in megawatts or radiation levels in microsieverts. The **principle of comparison** involves evaluating actual performance against these standards to detect deviations, such as comparing real reactor temperatures with safety limits. Once deviations are identified, the **principle of corrective action** calls for timely responses to restore normal conditions, such as adjusting coolant flow or shutting down the reactor safely. The **principle of responsibility** states that individuals assigned to control must also have the authority to act, illustrated by a shift supervisor's right to halt operations in case of danger. The **principle of efficiency** requires that control systems be cost-effective so that the benefits of control outweigh its costs, for instance, through automated monitoring that reduces the need for manual inspection. Finally, the **principle of flexibility** underlines that control must adapt to technological and environmental changes, such as updating monitoring procedures when new nuclear technologies are introduced. Together, these principles create a coherent and proactive control system that ensures safety, reliability, and efficiency in demanding environments like the nuclear energy sector.

The subject of control performs controlling in organizations, through the use of controlling techniques. Simply put, the notion of subject in controlling answers the question "who is doing the controlling?" Subjects can be both individual (e.g., manager, designated employee) and collective (e.g., board of directors, supervisory board, external control bodies, etc.). In certain areas, we can already observe inanimate systems (automatic control, artificial intelligence, etc.). The object of control is certain target systems, such as groups, individuals, and technical systems. Simply put, the notion of object in controlling answers the question "who is being controlled or what is being controlled?"

Classification of the control

Formal control - results from formal organization. It is determined by the position of the worker or unit within the hierarchy of the organization and the organization in the society in which it operates. In other words, it results from the organisational norms that the organisation has established for its activities and from the legislative norms that the organisation must base its activities on and respect. Formal control frameworks are set out in writing by management; informal control frameworks are derived from staff behaviour. Formal controls explicitly ensure that members of the organisation comply with the structures, policies, or procedures established by the organisation. They assist the organisation's management in planning and maintaining a strategy to achieve organisational objectives.

Informal controls - represent the unwritten determinants of behaviour and, in strong contrast to formal controls, may or may not be aligned with the objectives of the organisation and its management. It is constructed by employees who are responsible for maintaining and adapting the informal control system.

In theory, we also distinguish between **internal and external control**, or expressed synonymously as internal and external control.

Internal control means that the subject and the object come from the same system (**Operational monitoring:** Continuous tracking of reactor parameters like temperature, pressure, coolant flow by the plant’s control room. **Internal audits:** Regular reviews of safety documentation, maintenance records, and operational reports by internal audit teams. **Maintenance control:** Scheduled preventive maintenance of turbines, pumps, and cooling systems to prevent failures.).

External control means that the subject mostly comes from the external environment and does not form a single system with the object being controlled. The subjects of external control may come from public administration and public life, from the commercial sector or from the third sector (**Regulatory inspections:** Regular checks by the **national nuclear regulatory authority** to ensure compliance with safety laws. **Certification and licensing:** External verification before granting or renewing operational licenses for reactors or energy units.)

According to the literature, there is general and specific control. In the first type, the basic areas of the controlled organisational element and the critical criteria of its functioning are usually covered. It is not very common in practice because of its time-consuming nature. In specific control, the controlling entity focuses only on certain areas of activity, for example, those with the highest losses.

In classifying the types of controls according to the regularity with which they are carried out, there are two types of controls: regular and irregular. Some authors also refer to regular inspection as periodic inspection, and irregular inspection is divided into random, unscheduled, and extraordinary inspection.

Control can be divided into different areas (e.g., production, marketing, personnel), and it can also be divided by level within an organizational system:

- Operational control focuses on the processes that an organization uses to transform resources into products and services. Quality control is one type of operational control. Financial control deals with the financial resources of the organization. Monitoring accounts receivable to make sure that customers pay invoices on time is one example of financial control.
- Management control is concerned with how elements of the organizational structure serve their intended purpose. Monitoring the proportion of administration to make sure that personnel expenses do not exceed a tolerable level is an example of managerial control. It is also synonymously called structural control.
- Strategic control focuses on how effectively an organization's corporate, business, and functional strategies are able to support the organization in achieving its goals. For example, if a corporation has not been successful in implementing its strategy, akin to diversification, its managers need to identify the reasons and either change the strategy or renew their efforts for implementation.

A control process represents the activities and tasks performed to modify or correct a process or its results. If performance measurements vary, acceptable thresholds (variances) are exceeded, or a new opportunity is discovered, corrective action follows. The control process is intended to support the achievement of goals at all levels from the individual to the enterprise. Therefore, it needs to reflect these goals and a set of beliefs about the necessary behaviours to meet them. The control process is carried out by all departments and levels of management in an organization, and there are many variations in the application of control in different organizational areas. For example, in the production of vaccines for the Covid-19 disease, control will be considerably more rigorous than control in the production of an advertising campaign in an advertising agency.

The process of control is a five-step management function: establishing standards, measuring performance, comparing performance against standards, analysing any deviations, and taking corrective action if needed. This process helps ensure that an organization's activities and outcomes align with its goals and plans.

The five-step control process:

1. **Establish standards**: Set clear, measurable objectives and performance metrics.
2. **Measure performance**: Track and gather data on actual performance using reliable sources.
3. **Compare performance to standards**: Identify any gaps or deviations between the actual results and the established standards.
4. **Analyse deviations**: Determine the specific reasons why performance has deviated from the standards.
5. **Take corrective action**: Implement necessary changes to resolve issues and bring performance back in line with targets, or adjust standards if the environment has changed.

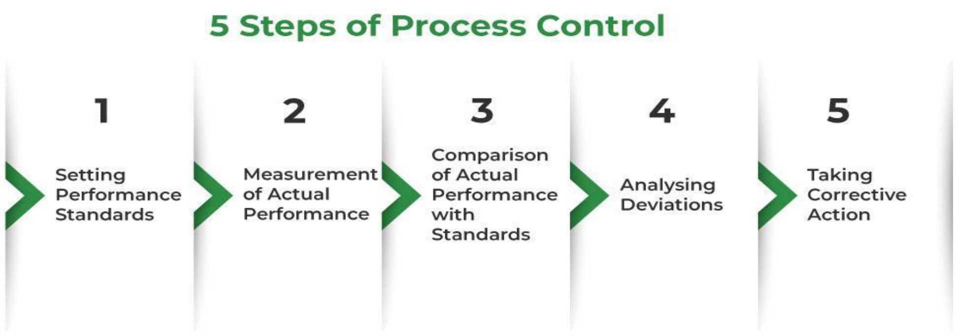


Figure 19.1: Process Control
Source: https://www.geeksforgeeks.org/business-studies/process-of-controlling/

The control processes should differ between types of organisation, particularly with regard to identifying the most appropriate performance indicators (in practice often KPIs or Key Performance Indicators) that should be used for a particular type of organisation. In the power and nuclear industries, the basic KPIs are by default linked to power generation and operations. For example, generation efficiency is measured through Capacity Factor (CF), which is a ratio of % capacity utilisation (ratio of actual to maximum possible generation). Another performance metric can be Customer Reliability, which measures the average length and number of interruptions to customer supply.

KPIs specific to nuclear power are for example:

- Radiation Exposure per Worker: average radiation dose to workers per year
- Forced Outage Rate (FOR): Percentage of time the reactor was out of service due to an unplanned malfunction
- Radioactive Release to Environment: Amount of radioactive substances released to air and water (Bq/year)

Feedback is an important element of an effective control process. It brings all the elements of the control mechanism together. The auditee receives information on actual performance against the original standards.

Setting performance standards is a prerequisite for a well-functioning control system. Standards provide the yardstick by which performance is measured so that any deviation between the standard and actual performance can be detected.

A control standard can be defined as a target against which subsequent performance can be compared. Standards developed for control purposes should be expressed in measurable units and should also correspond to the objectives of the organisation. They are generally expressed in terms of different variables such as quantity, quality, or time constraints. They can be as broad or as narrow as the activity to which they relate.

Performance standards attempt to answer questions such as "How much is enough work in a day?" or "What is a realistic daily productivity target?" Standards take into account many factors that can affect results, such as unavoidable delays or the time it takes to maintain equipment.

Quantitative standards should be set in such a way that they can be achieved within tolerance limits. They shall be determined on the basis of past performance data or future forecasts, taking into account external influences. For example, in the power and nuclear industries, there are measurable quantitative standards:

- Capacity Factor - the ratio of actual electricity production to the maximum possible; target > 90%.
- Emergency system response time - time from detection to activation of the safety system, measured in seconds.
- Number of violations of technical specifications - quantitative indicator of nuclear safety (NSA)

Qualitative standard is a concept that covers all kinds of standards that cannot be expressed numerically with a sufficient degree of certainty. Examples of qualitative standards could be:

- Safety Culture - the degree to which all employees accept safety as a top priority; it is assessed through audits, questionnaires, observations, and incident reports.
- Quality of maintenance and procedures - e.g., whether procedures are clearly described, updated, and understood by staff.

Laws and various regulations also tend to be the basis for standards. Indeed, the performance achieved must comply with certain regulations concerning the disposal of hazardous substances, equal employment opportunity principles, or occupational safety. Such as:

- ISO 6215:1980 (Nuclear power plants - Quality assurance) - older standard, specifically for nuclear power plants.
- ASME NQA 1:2024 (technical norm: Quality Assurance Requirements for Nuclear Facility Applications)
- ISO 19443:2018 (Quality management systems - Specific requirements for the application of ISO 9001:2015 by organisations in the supply chain of the nuclear energy sector supplying products and services important to nuclear safety).

Comparing Standards and Performance, Taking Corrective Action

Process of Comparing Standards and Performance This stage involves **evaluating actual results against established standards or goals** to determine whether operations are proceeding as planned. Managers measure current performance using reliable data (e.g., production output, efficiency rate, safety indicators) and compare it with benchmarks or targets set in advance. Any **deviation** — whether positive or negative — indicates that action may be needed.

Example (Energetics): A nuclear plant’s planned reactor temperature is 320°C. Daily monitoring shows it reaching 328°C. This deviation signals a potential cooling system issue that must be analysed.

Process of Taking Corrective Actions Once deviations are identified, managers must **analyse their causes** and **implement measures to correct them**. Corrective actions can be **immediate** (e.g., adjusting equipment parameters) or **long-term** (e.g., revising maintenance schedules, retraining staff, or upgrading technology). The goal is to bring performance back in line with standards and prevent similar issues in the future.

Example (Energetics): After detecting a temperature deviation, engineers inspect the cooling system, find a partially blocked pipe, and clean or replace it. Management then updates maintenance procedures to prevent recurrence.

Control is a continuous process where managers **compare actual performance with set standards, identify deviations**, and **take corrective actions** to ensure that operations remain safe, efficient, and aligned with organizational objectives.

Options for reducing or eliminating the need for control

Automation is currently a very common option to not only make work more efficient, but also to significantly reduce the need for control. The problem with standard activities is the human factor, which is not always able to deliver the same performance or show variations in results. Computers and other means of automation reduce an organisation's exposure to control problems because they can be set to perform correctly. Thus, in the way the organisation wishes. On the one hand, automation tools perform the task more consistently than humans; on the other hand, they are not shy to report an error that was caused by them. They are not afraid of being penalised. For example, whereas previously managers or human resources people had to check attendance sheets themselves, with the introduction of smartcards, the automated system has taken over. The manager no longer has to worry about overlooking an employee's signature, and the employee no longer has to worry about signing in the wrong box. Errors are minimised. When an employee forgets their card, the responsible employee can still enter the system and record the attendance.

In the case of the power and nuclear industries, automation is being used:

- Smart Grids - automatically balance electricity supply and demand, responding to changes in consumption, outages or renewables.
- Automated Electricity Trading Algorithms (Energy Trading Algorithms) - systems predict consumption and prices, buy/sell energy on exchanges in real time.
- Predictive Maintenance - sensors and AI models evaluate vibration, temperature, and component consumption to predict failures before they occur.
- Power Plant Control - Automated controllers regulate turbine, combustion, or cooling power according to the current load on the grid.

Centralization means that decision-making authority is concentrated at the top levels of an organization. In other words, most important decisions are made by senior management, and lower-level employees mainly follow established procedures and guidelines. When an organization is highly centralized, **the need for extensive control systems** (like constant supervision, performance monitoring, or detailed reporting) can be **reduced** or even **partly eliminated**.

Table 19.1: Centralization properties

Effect of Centralization	How It Reduces Need for Control	Example in Energetics
Standardized procedures	Everyone follows the same rules	Centralized safety protocols
Clear authority	Less supervision needed	Central control team approves key actions
Simplified communication	Fewer reporting levels	Direct data flow to headquarters
Unified goals	Fewer inconsistencies to monitor	One energy trading strategy for all plants

Risk sharing represents a third option to reduce the need for control. The organisation shares the risk with an external entity, such as an insurance company, so that the organisation does not bear the full consequences in the event of a serious loss. For example, many reputable companies insure employees in sensitive positions, thereby reducing the likelihood that employee behaviour will cause significant damage to the organisation. Every nuclear power plant in Slovakia is required to have nuclear liability insurance by specific law. Operators of critical infrastructure, including nuclear power plants, insure key personnel (e.g., reactor unit managers, radiation safety specialists, IT security).

CHAPTER 20: LEADING PEOPLE IN ORGANIZATIONS AND COMMUNICATION PROCESS

The core of leading people, leadership styles

The view of the leadership has evolved and changed over time, as has society itself. When we look at the 20th century, we find different periods in which managers appeared more like entrepreneurs (early 20th century), in the 1950s, the view of managers changed, and organisational types of managers emerged. In the 1970s, a phenomenon emerged: the manager as strategic leader. It is certainly important for the right leader to be able to fulfil each of these functions - to be an entrepreneur, an organisational manager, as well as a strategic leader. However, current studies and research attribute to them additional qualities that inevitably arise from a dynamic external environment, such as change management, flexibility of thought, adaptability, ideas and creative thinking, the art of listening, perception, the ability to build effective teams and manage group dynamics, and the ability to motivate and communicate effectively. Leadership is sometimes incorrectly identified with management. Management is a much broader concept than leadership. Leadership is part of management, not all of management. In the literature, it is often referred to as one of the core management functions. In management, managers have to plan, organise, control, and also lead people to achieve objectives. The best performing managers tend to be effective leaders, yet management is more than leadership. Management involves careful planning, creating an organizational structure that helps people achieve goals, and filling each position with the most capable people. In management theory, leading people occurs as one of the functional areas of management, and along with planning, organizing, and controlling, leading people is a prerequisite for successful managerial work.

A formal managerial position is no guarantee of effective leadership. Just because someone is in a leadership position does not mean that they have certain responsibilities. Being a leader and not just a manager is a position that subordinates recognize. Gaining trust requires effort beyond that of a typical manager. However, this effort to gain trust is certainly worthwhile. Once leadership is recognized, job performance and personal relationships tend to show substantial improvement. Leadership has at least three aspects: leadership in terms of personal characteristics, in terms of style, and in terms of function. It is a complex composite of all of the above factors.

The essential difference between a leader and a manager, even according to the previous definitions, lies precisely in the ability to create a vision. The manager usually focuses on the present and the implementation of day-to-day activities.

Power or authority is a prerequisite for leadership. These concepts are often interpreted in different ways. Power is sometimes seen as a broader concept than authority. It is the ability of individuals or groups to change or influence the views or behaviour of other members or groups.

Authority is the right to direct the actions of others. It is an officially confirmed privilege that may or may not secure results. In contrast, power demonstrates the ability to achieve results. Power is often described as the ability to impose one's will on others. In theory, we recognise six sources of power:

- **Legitimate power:** Authority granted by a formal role or position within an organization or society.
- **Reward power:** The ability to grant rewards, such as raises, promotions, or bonuses.
- **Coercive power:** The ability to punish or force someone to comply through threats or negative consequences.
- **Expert power:** Influence derived from a person's knowledge, skills, or expertise.
- **Referent power:** Power based on a person's charisma or on the admiration and respect others have for them.
- **Informational power:** The ability to control and share or withhold information.

Traditional leadership styles are based on the use of the supervisor's authority. On this basis, we recognize the following three styles.

Authoritative (autocratic, directive) leadership style - all authority is concentrated on the manager. Communication is centrally oriented to the manager and is implemented in a top-down direction, using punishments and rewards to implement decisions. Harsh discipline is required in following orders. The advantage of this style is speed of decision making, the disadvantage is weak work group support.

Democratic (participative) leadership style - the group leader takes into account the wishes and desires of the group members. The leader acts as a coordinator, directs the progress of work, assists in the performance of duties, and discusses the results with subordinates. The advantage of this style of leadership is the growth of morale of group members, their support, and higher quality of decisions. The disadvantages are slowness and cumbersomeness, and in certain circumstances, the boundary of personal responsibility is lost.

Liberal (Laissez-faire, free-flowing) leadership style - the leader rarely uses his or her power and leaves a great deal of freedom of action to co-workers, so they are largely independent. This leadership style can mean creating opportunities for individual growth. Subordinates set their own goals and the means to achieve them; the leader helps only to provide information and liaison with the external environment. He acts as a representative of the work group. The disadvantage is that lability occurs, and the relationship between individual and group performance is severely eroded, resulting in a loss of group cohesion.

J. Mouton and R. Blake are the authors of the managerial grid theory, which is a two-dimensional square matrix with 9x9 cells in which the horizontal arrangement of cells from 1 to 9 expresses managers' interest in production (task orientation) and the vertical arrangement of cells from 1 to 9 means interest in people (people orientation).

Definition of the two dimensions used in the managerial grid:

Concern for production: This is the degree to which a manager is focused on achieving goals, efficiency, and task completion.

Concern for people: This is the degree to which a manager is concerned with the well-being, needs, and emotional state of their team members.

Authors placed several management styles in this diagram and labelled them with coordinates:

- Country club manager (1,9) or also the neighbourhood type attends carefully to people's needs in order to satisfy relationships that lead to a pleasant, friendly organisational atmosphere and a tolerable work pace. Attention is paid to creating good relationships between colleagues and subordinates, often at the expense of work accomplishments.
- Team leader (9,9) achieves work results by engaging people. A sense of sharing a 'common edge' in the organisation leads to trusting and collaborative relationships. The team leader is goal-oriented through the application of teamwork approaches to achieve optimal results through participation, commitment of workers, and collaborative problem-solving. The work group resembles a sports team.
- Impoverished manager (1,1) also referred to in the literature as an indifferent leader, expends minimal effort to get the required work done, and is oblivious to the needs of the workers. He or she tries only to the extent necessary to survive in his or her position. He is an apathetic leader, exercises only formal control, and blames others for failure.
- Authority-Compliance Manager (9,1) is a leader who is solely devoted to completing tasks and achieving the highest possible work performance, relying on power and authority, consistently controlling people, telling them what to do and how to do it. Performance in operations management is associated with minimal attention to people problems. He is impervious to criticism and does not distinguish between man and machine.
- Middle-of-the-road manager (5,5) achieves adequate performance by balancing the need to accomplish tasks acceptably on the one hand and to maintain tolerable morale on the other. The compromise type of leadership is a happy medium; it is practical, pragmatic, and tends to compromise and negotiate.

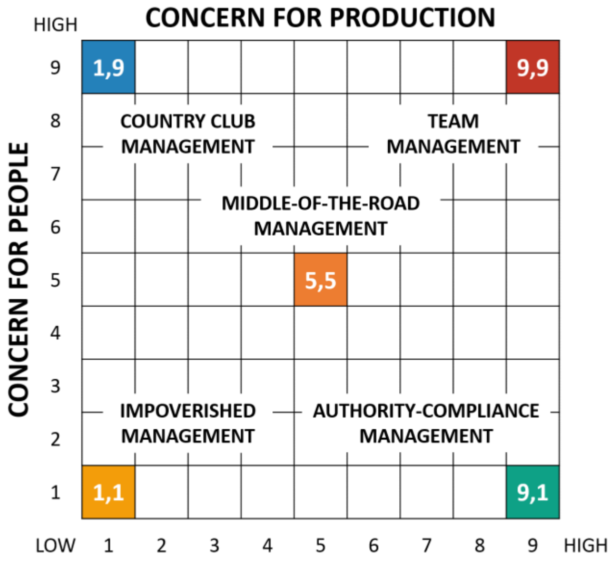


Figure 20.1: Management styles

Source: https://www.business-to-you.com/blake-mouton-managerial-grid/

The situational approach describes the leadership of people through a fundamental factor, namely the specific situation, which is influenced not only by the personality of the leader, but also by subordinates, their relationships with each other, the quality and difficulty of the work task, the work environment, and other external obstacles and factors such as the quality of information, internal company processes, the level of formal and informal communication

Situational leadership is based on the assumption that the choice of the right leadership method is often, if not always, conditioned by the situation. The maturity of the staff is most often taken into account as a basic condition of the situation when choosing leadership methods (authors P. Hersey and K. Blanchard). The measure of maturity is the readiness to perform the task. We distinguish between work maturity (this is determined by the skills and technical knowledge needed to perform the task) and psychological maturity (it consists of the readiness of the followers to accept responsibility for performing the task).
A leader should choose a leadership style that develops the maturity of his/her staff. A leader's behaviour can be described in two dimensions - supportive behaviour (praise, listening, and facilitation) and directive behaviour based on structure, control, and supervision. Four basic situational leadership styles are:

- directing - a high degree of directive behaviour and a low degree of supportive behaviour. It is used with immature people who are inexperienced, who are getting bogged down in tasks, who need to be commanded and guided step by step, who need to be told exactly what to do and how to do it, and who need to be constantly supervised and controlled.
- coaching - a high degree of directive behaviour and a high degree of supportive behaviour. It is used when, on the work side, subordinates have reached a certain level of competence, and the supervisor can focus more on the interpersonal aspects of the task. The leader

coaches them, i.e., pays much more attention to people and their handling of interpersonal relationships;

- supporting - a low degree of directive behaviour and a high degree of supportive behaviour. The leader progressively limits the attention paid to people as they learn to manage their conflicts on their own.
- delegating - delegating occurs when a worker is mature both professionally and psychologically, managing work tasks independently without a supervisor. The manager tends to help in overcoming emergencies and deals mainly with matters of a strategic nature.

The communication and components of the communication process

Since communication accompanies all work situations and processes that take place at work from morning to night in verbal, non-verbal, formal, or informal form, there is a need to be able to communicate effectively at the level of the organisation, management, and employees. If communication can be managed adequately, it is an excellent tool to influence employee motivation, performance, satisfaction, teamwork, commitment, and loyalty.

The constant flow of information is an essential part of communication in a company. Information is a fundamental component of managerial communication. A manager needs to obtain a certain amount of information in order to be able to evaluate the situation and make decisions in the process. In this context, it is necessary to distinguish concepts such as data, information, and knowledge with which people in the organization work. The success of an organisation is often based on the skill of how to handle and use information.

Data is any message, regardless of whether it has any information content for us or not, i.e., whether the message tells us something new or is irrelevant at the moment. In practical terms, data are objective facts about some fact, process, or element of the real world. Data can be letters, numbers, words, characters, or combinations thereof. They are general statements describing reality. All data carry some information content that can be assessed quantitatively or qualitatively.

Information is data that has interpretive meaning, i.e., it has a specific predictive value, relevance, and meaning to the data user. It serves some purpose or triggers some action. Information is considered to be a specific communication that the recipient can interpret and use in time and space. Based on recipient **knowledge**, users assign a subjective character to data. If the manager has sufficient knowledge to process the available data, the data yield the utility value needed, for example, to reduce risk in the decision-making process.

Examples of data – information – knowledge relations:

Data:
Cooling water inlet temperature: 28.7 °C
Cooling water outlet temperature: 42.3 °C

Information:
The temperature difference between the inlet and outlet is 13.6 °C, which is 2 °C higher than the optimal range specified for efficient heat exchange in the cooling system.

Knowledge:
The increased temperature difference indicates reduced heat transfer efficiency, likely due to biofouling or scaling in the condenser tubes. Action: Schedule cleaning and inspection of the cooling system to restore efficiency and prevent reactor overheating risks.

The communication process is internally structured; it is made up of relatively separate components, the intensity and quality of which influence the overall course of communication. It is essential for the manager to be aware of how the individual components of the communication process work and to use them in the management process. The individual components of the communication process that make up and influence the course of communication are: communicators - sender and receiver, message, medium, context, feedback, and communication noise.

Sender (communicator)

The sender is the person who sends a message to the receiver. They assume that the receiver has enough knowledge to understand it. The sender also expresses their personality, attitude toward the receiver, and expected reaction through the message. Communication can be influenced by factors such as age, education, gender, experience, or environment.

Receiver (communicant)

The receiver is the person who gets the message from the sender. How well they understand it depends on their knowledge, experience, personality, expectations, and possible biases. The receiver's task is to listen or read the message, decode it, and interpret its meaning. It is important to pay attention to both the content and the nonverbal or linguistic signals.

Message (communication)

A message is the specific piece of information or idea sent by the sender. It has content and a code. The **code** is a set of symbols and rules shared (to some degree) by both parties.
Encoding means turning ideas into symbols, words, or images.
Decoding is translating those symbols back into thoughts.
Messages can be verbal, written, electronic, or nonverbal. If the sender and receiver don't share the same code, communication will not be effective.

Medium (channel, tool)

The medium is the path through which information travels. In direct communication, the main channels are verbal and nonverbal signals (words, tone, gestures, looks, movements, etc.). In mediated communication, channels include phones, mass media, written forms, emails, social media, or online platforms. The sender should choose an appropriate channel and be aware of each one's limitations.

Context (situation, environment)

Context includes the conditions under which communication takes place and strongly affects

its success.
It includes both: **physical context**, where communication happens (office, meeting room, noise, lighting, etc.), and **psychological and social context**: mood, previous experience, emotional readiness, trust, etc.

Feedback

Feedback is the receiver's reaction to the message. It is a key element because it shows whether the message was understood correctly. Feedback can be: verbal (spoken words), nonverbal (facial expressions, gestures), or written (notes, messages, emails).
It helps the sender see the communication's result and make corrections if necessary. Without feedback, the sender cannot be sure the message was correctly understood.

Communication Noise

Noise means distortion or loss of information during the communication process. It occurs in the stages of encoding, transmission, or decoding. Although noise cannot be completely avoided, it can be reduced by using clear language, empathy, active listening, and feedback. Types of noise and barriers include:

- Physical noise – external distractions such as street sounds, loud music, or machine noise (loud machinery or turbine noise in a power plant makes it hard for engineers to hear each other during maintenance).
- Physiological noise – internal barriers like illness, tiredness, or pain (A tired operator mishears instructions during a night shift).
- Semantic noise – misunderstandings caused by different meanings, languages, dialects, or complex terms (A project manager uses too much specialized nuclear terminology when talking to non-technical staff).
- Psychological noise – mental barriers such as closed-mindedness, distrust, bias, or emotional sensitivity (A team member under stress or fear of failure misinterprets instructions).
- Cultural noise – misunderstandings caused by different cultural norms or interpretations, often through nonverbal signals (an international consortium, engineers from different countries interpret gestures or levels of formality differently).

External and internal communication is very important for the growth and performance of an organisation. They are two different ways of communicating aimed at different audiences and require different skills and approaches from managers. Nevertheless, for the successful functioning of an organization, it is essential to align external and internal communication and provide the same information in all directions. If they do not work together, they will send inconsistent and mixed messages, which can lead to confusion and uncertainty on the part of employees, customers, and the public. It is therefore essential to approach internal and external communications together

Internal communication can take place in three communication directions, namely vertical, horizontal or diagonal.

Vertical communication is two-way communication using different levels of feedback. It reflects the status and relationships of superiority and subordination of the various entities that enter into internal communication. The level of vertical communication has an impact on employee productivity, motivation, accountability, and performance. Well-established vertical communication removes tension, eliminates errors, promotes competitiveness, facilitates adaptation to new conditions, and shapes feelings of belonging and loyalty. As a rule, it takes place in two directions: top-down (manager-subordinate) and bottom-up (subordinate-manager), in formal and informal forms.

Horizontal communication takes place between managers or employees in the organisation who have equal or equivalent status within the hierarchy. It can be formal (discussion and exchange of information when solving tasks, coordinating activities and processes, planned meetings of experts, etc.) or informal (spontaneous communication between employees, sharing of experiences, etc.). Horizontal communication reflects the socio-psychological atmosphere in the company and the relationships between employees.

Diagonal (cross) communication is the flow of information between employees of different hierarchical levels, without necessarily having a direct organisational link between them. The benefits are mainly to speed up communication, increase its efficiency, improve coordination, and eliminate problems due to lengthy decision-making. It takes place especially where cooperation is essential. It mainly uses the communication of a large group of people in a predominantly oral form, such as meetings, guided discussions, conferences, training sessions, collective bargaining, or the coordination of the tasks of managers of different departments, in the process of project management.

In terms of managerial communication, it should be added that communication in the workplace is both **formal and informal**. Formal communication guides communication with employees in order to achieve the organisation's objectives. It takes place in accordance with officially recognised rules that are binding on all. A significant part of it consists of pre-prepared structured information, reports, orders, etc. In terms of direction, it is predominantly vertical communication. Within the organisational structure, communication flows are precisely defined (who communicates with whom, who is responsible for whom, with whom specific tasks are dealt with, who delegates, who provides information, etc.). At the same time, the formal communication competences and responsibilities of all employees and managers are defined. If the rules of formal communication were not precisely defined, organisational and communication chaos would ensue in the organisation.

Informal communication takes place at the vertical level, but more often at the horizontal level. It can be of a working nature (exchange of views, ideas, consultation) or take the form of a non-binding private conversation. It arises against the background of formal communication and represents an informal exchange of information between different people. The communication relationship and the communication situation are not governed by formal rules and guidelines, but arise from the actual situation in the organisation and the needs of the individuals. It takes place both in the workplace and outside it. Informal communication is often more flexible than formal communication and can compensate for the shortcomings of formal communication. An experienced manager uses informal communication to elicit opinions about a problem and its solution. Informal communication results in the formation of informal groups and relationships, which can positively develop formal communication but can also be disruptive and counterproductive. The formation of an informal communication network can arise from a perceived lack of official information, which has negative consequences (dissemination of incomplete, untrue, unverified information, dissemination of 'secret' information based on personal contacts).

Comparison of motivation, stimulation, and engagement

Motivation represents the **inner driving force** that leads a person to act in a certain way and strive to achieve both **personal and organizational goals**. It is **internal and psychological**, arising from individual needs, values, and aspirations. In essence, motivation answers the question *"Why do I want to do this?"* For example, a nuclear engineer might be motivated by a desire to contribute to clean energy or professional excellence. The American psychologist **Abraham Maslow** proposed that human motivation is based on a hierarchy of needs. People are motivated to satisfy **basic needs first**, and only after those are met do they seek to fulfil **higher-level psychological and self-fulfilment needs**. The five levels are: **physiological needs** (food, water, sleep), **safety needs** (security, stability), **love and belonging needs** (friendship, intimacy), **esteem needs** (recognition, respect), and **self-actualization** (achieving one's full potential).

Figure 8.2: Maslow's hierarchy of needs

Source: https://www.simplypsychology.org/maslow.html

Stimulation, in contrast, comes from **external influences**. It refers to the **intentional effort of another person or organization to affect someone's motivation** using rewards, recognition, or other stimuli. While motivation originates from within, stimulation is a **tool used by management to awaken or strengthen motivation**. For example, a plant manager may stimulate employees through bonuses for safety compliance or through opportunities for career advancement.

Engagement reflects the **visible result** of effective motivation and stimulation - a **state of deep commitment and enthusiasm toward work and the organization.** An engaged employee doesn't just fulfil duties but actively seeks improvement, innovation, and teamwork. Engagement thus represents a **higher level of motivation**, where personal and organizational goals align. For instance, an engaged worker in a nuclear plant consistently follows safety procedures not just because they must, but because they genuinely care about collective success and operational excellence.

Motivation is the internal will to act, **stimulation** is the external influence that shapes or reinforces it, and **engagement** is the resulting state when motivation and stimulation align, leading to high performance and organizational commitment.