Mala enciklopedija jedrske energije

Mini Encyclopaedia of Nuclear Energy

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Uvod

Električna energija je gonilo sodobnega sveta in predstavlja merilo razvitosti določene države ali družbe. Od sredine dvajsetega stoletja uporabljamo za proizvodnjo elektrike tudi jedrsko energijo. Danes, šestdeset let po začetku obratovanja prve komercialne jedrske elektrarne, te proizvajajo v svetu približno sedmino, v Evropi pa približno tretjino vse električne energije.

Začetek uporabe jedrske energije je spremljal splošen optimizem, značilen za čas po koncu druge svetovne vojne. Obetala je rešitev mnogih težav takratnega sveta. Začeli so graditi jedrske elektrarne in ladje na jedrski pogon. Sčasoma je jedrska energija pokazala tudi svoje pomanjkljivosti. Dve resni nesreči v času, ko je bila jedrska energija že splošno uveljavljena, sta zadostovali, da se je prvotno navdušenje v mnogih državah sprevrglo v nasprotovanje. Nesreča v Fukušimi, ki jo je sprožila naravna katastrofa, je bila povod, da se nameravajo nekatere države odpovedati jedrski energiji. Več držav pa svoje jedrske zmogljivosti obnavlja in širi.

Kljub očitnim koristim jedrske elektrike je javnost zaskrbljena zaradi možnosti jedrske nesreče in radioaktivnih odpadkov. Radioaktivnost se zdi ljudem skrivnostna in nevarna, ker ni dostopna našim čutom, čeprav je od nekdaj prisotna tudi v naravnem okolju. Kompleksnost izkoriščanja jedrske energije in radioaktivnost je težko pojasniti posameznikom, ki si za to ne vzamejo vsaj nekaj časa in truda.

V zadnjem času vzbuja vse več pozornosti tudi pojav podnebnih sprememb zaradi sproščanja ogljikovega dioksida, ki utegne postati ena najhujših groženj velikemu delu človeštva. EU se je v svojem energetsko-podnebnem paketu zavezala do leta 2020 zmanjšati emisije CO_2 za 20 % primerjavi z letom 1990. Jedrske elektrarne so poleg hidroelektrarn edini veliki, komercialno dostopni vir električne energije, ki ne sprošča CO_2. V tej luči je jedrska energija dobila čisto nov pomen.

S pomočjo Male enciklopedije želimo posameznikom iz splošne javnosti omogočiti, da na osnovi poljudnih razlag in ilustracij spoznajo jedrsko tehnologijo in radioaktivnost ter si sami ustvarijo mnenje o njenih prednostih in pomanjkljivostih.

Več informacij dobite na:

More information available at:

www.icjt.org
www.nek.si
www.gen-energija.si
www.svet-energije.si
www.ursjv.si
www.arao.si

Foreword

Electricity drives the modern world and is an indication of the economic status of a country or a society. From the mid-twentieth century, we have also been using energy from nuclear fission for conversion into electricity. Today, sixty years after the start of operation of the first commercial nuclear power plant, one seventh of the electricity in the world and one third in Europe is generated in nuclear power plants.

The beginning of the peaceful use of nuclear power in the post-war world was very optimistic. It promised a solution to many problems of that time. Nuclear power plants and nuclear-powered ships were constructed. Over the years the disadvantages of nuclear power also became apparent. Two serious accidents at the time when nuclear power was already firmly established caused waning of the initial enthusiasm. Opinion has turned the other way in many countries and some have decided to phase out nuclear energy after the Fukushima accident. Nevertheless several countries renew and expand their nuclear capacities.

The general public consider the possibility of a major accident and the disposal of radioactive waste serious problems. Radioactivity, though part of the natural environment, has always seemed mysterious and dangerous because it is not accessible to our senses. It is difficult to explain the complexity of nuclear power and radioactivity to someone who is not prepared to take some time and effort.

Recently, global warming due to release of carbon dioxide is attracting more attention because this might seriously endanger a large part of mankind in the future. The EU is committed to reducing its overall emissions of CO_2 at least 20% below 1990 levels by 2020. Nuclear power, besides hydropower, is the only large commercially available source of energy that does not release CO_2. This fact gives a whole new value to nuclear power.

This Mini Encyclopaedia, prepared by experts at the Nuclear Training Centre, tries to explain the basic facts about radioactivity and nuclear technology in an easy-to-understand way. Only a good understanding can help each individual form his or her independent opinion about the benefits and problems of these technologies.

Vsebina

Contents

Energija

Energy

Energijo potrebujemo za gibanje in življenje.

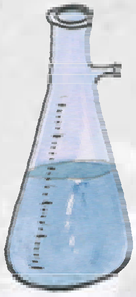
Energy is essential for movement and life.

Energija obstaja v različnih oblikah, ki se lahko spreminjajo iz ene v drugo.

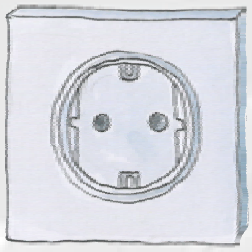
Energy comes in several different forms that are interchangeable.

Energija gibanja Kinetic energy

Kemična energija
Chemical energy



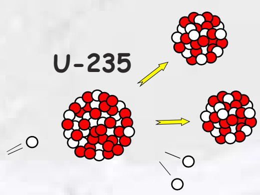
Električna energija Electrical energy



Toplotna energija
Heat

Svetlobna energija
Light energy

Jedrska energija
Nuclear energy



Osnovna enota za energijo je džul (joule) – **1 J**

Običajno uporabljamo kilovatno uro (kWh)
1 kWh = 3 600 000 J

Z 1 kWh, ki stane približno 0,1 €, lahko npr. skuhamo kosilo.

The basic unit of energy is the Joule – **1 J**

A commonly used unit is the kilowatt-hour (kWh)
1 kWh = 3 600 000 J

Cooking a lunch requires about 1 kWh, which costs around 0.1 €

Moč

Power

Moč pove, koliko energije porabimo ali proizvedemo v določenem času.

Enota za moč je vat (watt) – 1 W
V praksi uporabljamo enoti 1 kW = 1000 W
1 MW = 1000 kW

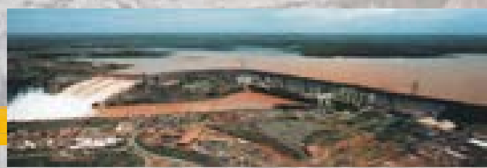
Power describes the energy used or produced in a given time.

The unit of power is the Watt – 1 W
The units used in practice are 1 kW = 1000 W
1 MW = 1000 kW

Primerjava moči

Power Comparison

Vesoljska raketa
Space rocket
100 000 MW

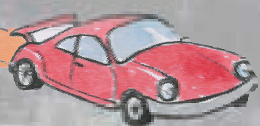


Hidroelektrarna Itaipu (Brazilija)
Itaipu hydroelectric power plant (Brazil)
13 000 MW

NE Krško
Krško NPP
700 MW

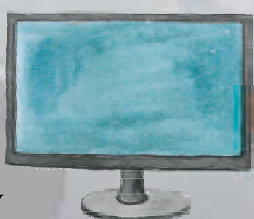
HE Mavčiče
Mavčiče hydroelectric power plant
40 MW

Električna lokomotiva
Electric locomotive
3 MW

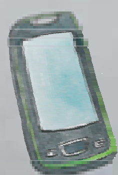


Avtomobil
Automobile
200 kW

Atlet
Athlete
1 kW



TV
200 W



Mobilni telefon
Cell phone
1 W

Od primarne do koristne energije

From Primary to Useful Energy

Primarna energija izvira iz naravnih energetskih virov.

Primary energy sources exist in nature.

Koristna energija znaša tipično 1% – 30% primarne

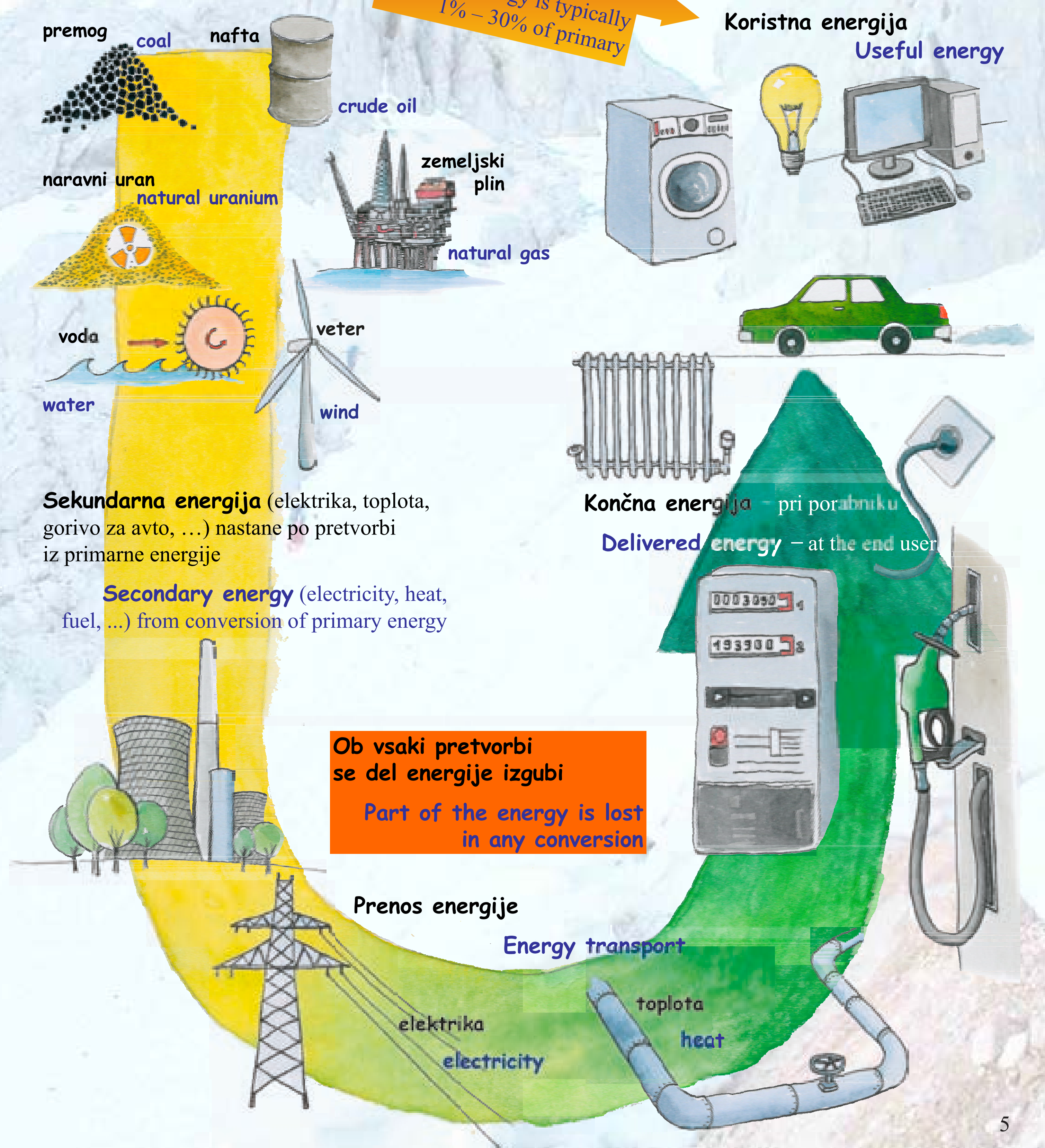
Useful energy is typically 1% – 30% of primary

Sekundarna energija (elektrika, toplota, gorivo za avto, …) nastane po pretvorbi iz primarne energije

Secondary energy (electricity, heat, fuel, ...) from conversion of primary energy

Ob vsaki pretvorbi se del energije izgubi

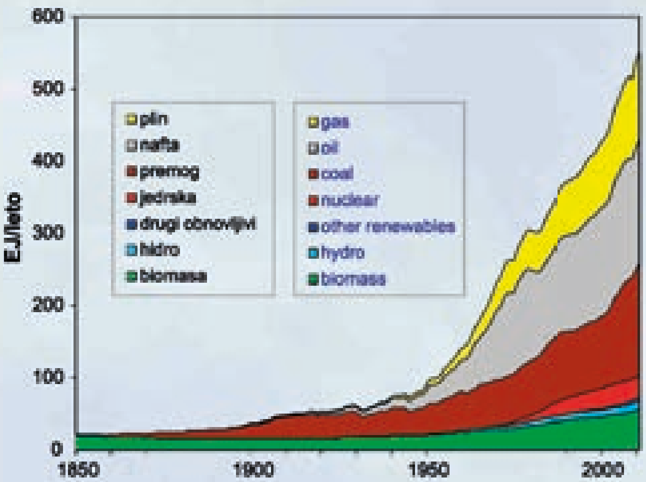
Part of the energy is lost in any conversion



Poraba energije

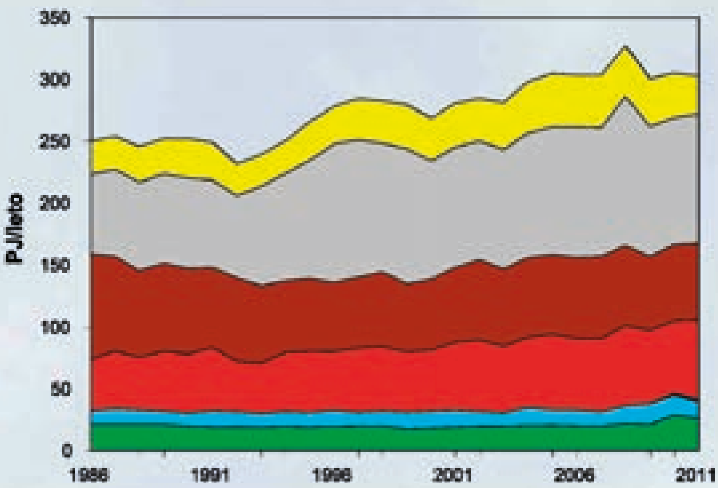
Energy Consumption

Svet — World



1 EJ (exa joule) = 10^{18} J

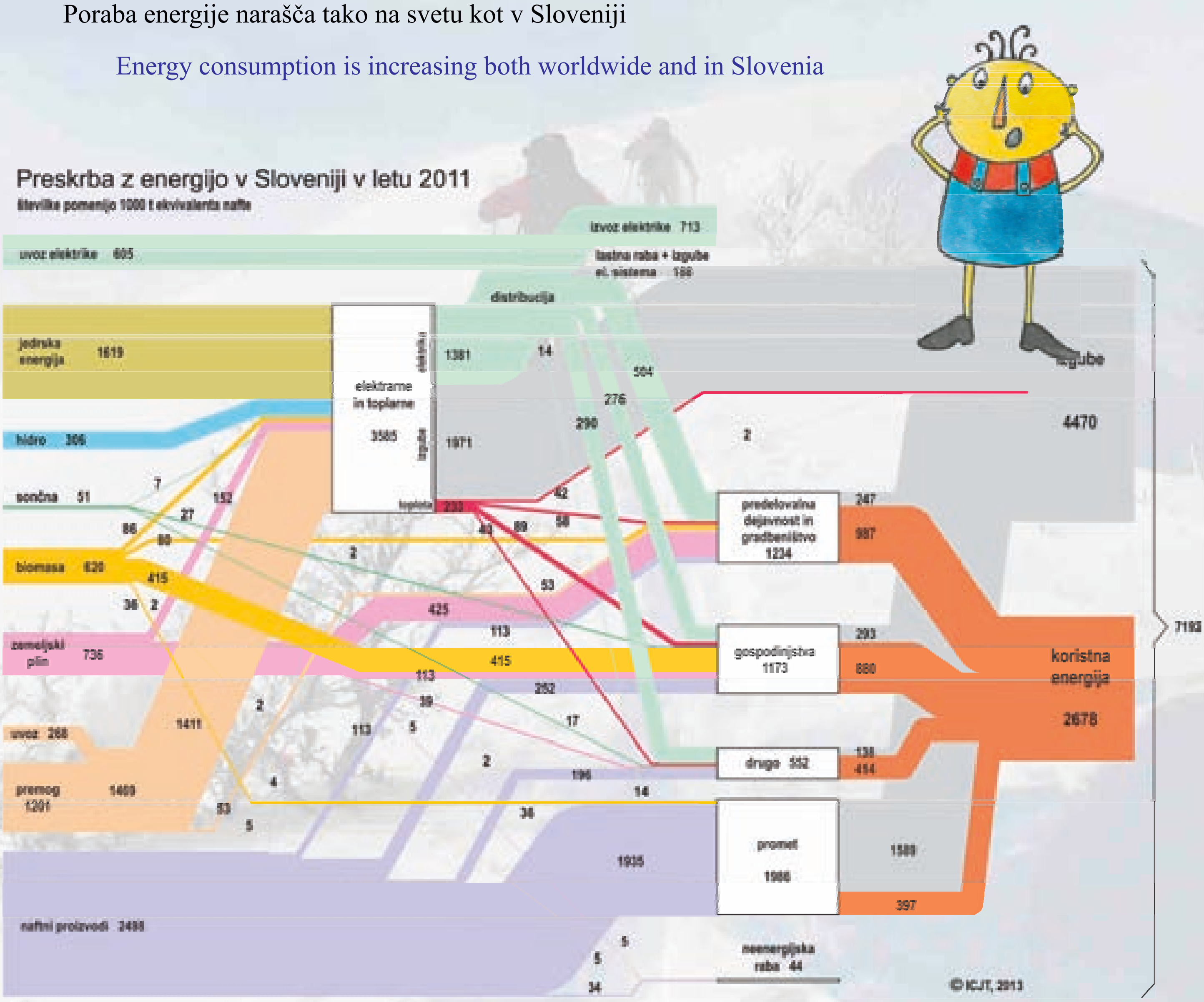
Slovenija — Slovenia



1 PJ (peta joule) = 10^{15} J

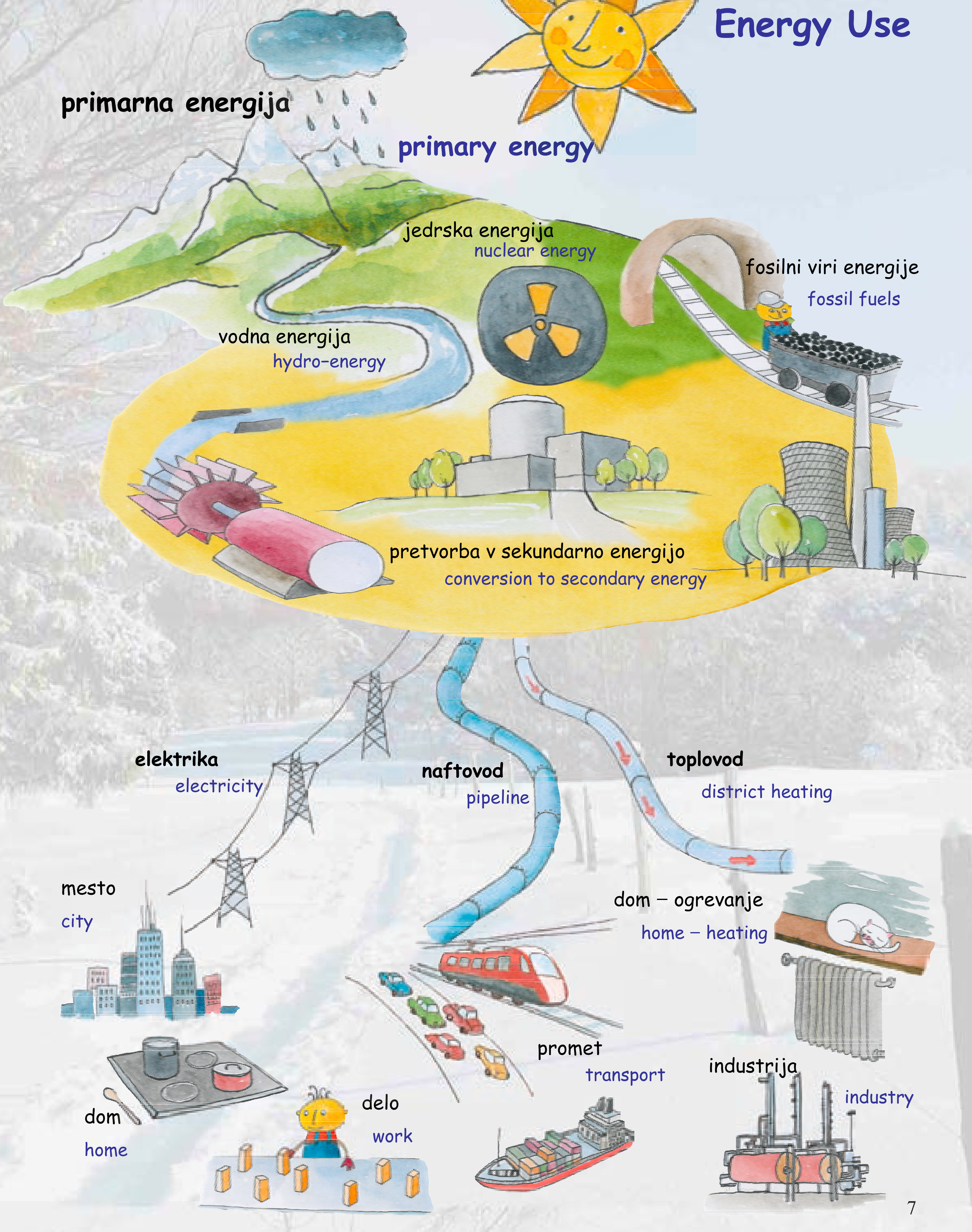
Poraba energije narašča tako na svetu kot v Sloveniji

Energy consumption is increasing both worldwide and in Slovenia



Načini uporabe energije

Energy Use



Učinkovita raba energije

Manj energije za **enak** končni učinek

Efficient Energy Use

Using **less** energy for the **same** energy effect

- toplotna izolacija stavb
- soproizvodnja elektrike in toplote
- sodobne elektrarne
- varčne sijalke
- moderni avtomobili
- učinkoviti gospodinjski aparati

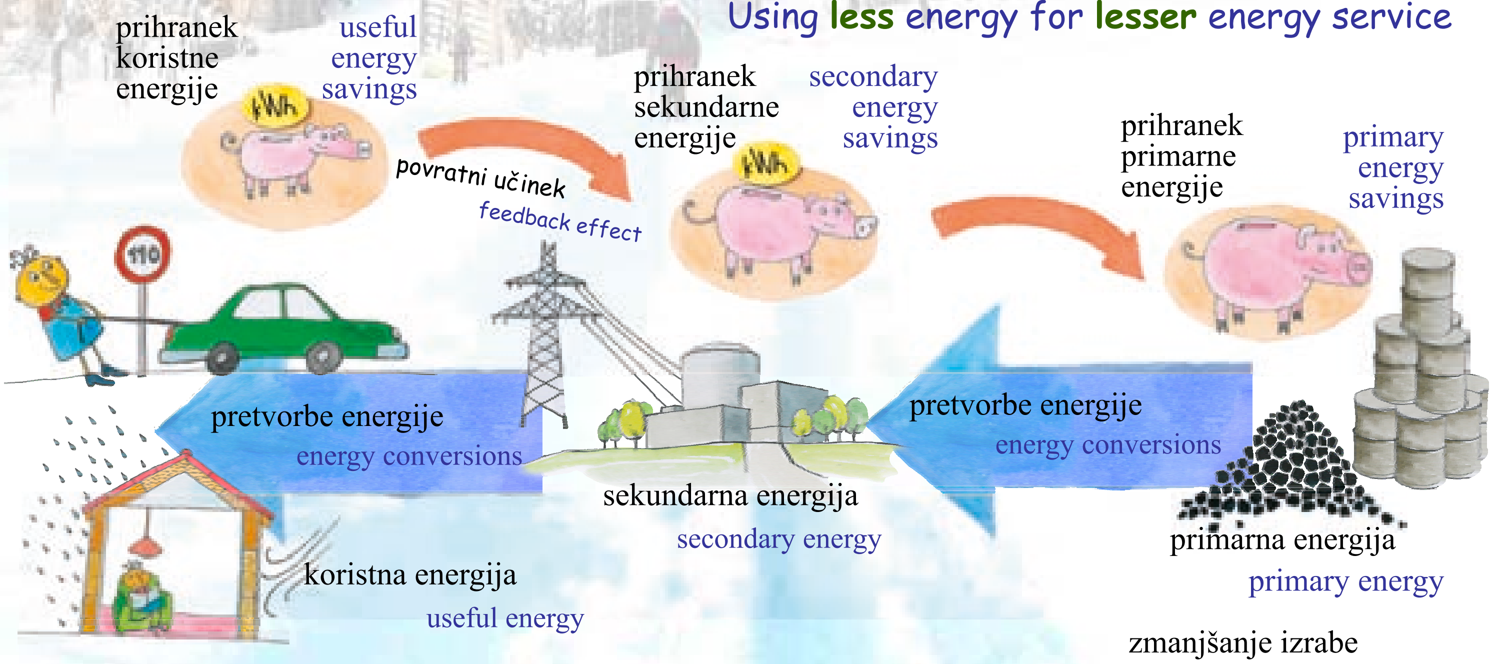
- thermal insulation of buildings
- cogeneration of electricity and heat
- advanced power plants
- efficient lighting
- advanced cars
- efficient home appliances

Varčevanje z energijo

Manj energije za **manjši** končni učinek

Energy Conservation

Using **less** energy for **lesser** energy service



zmanjšanje izrabe naravnih virov

reduction in use of natural resources

- počasnejša vožnja
- manj osvetlitve
- manj ogrevanja in klimatiziranja

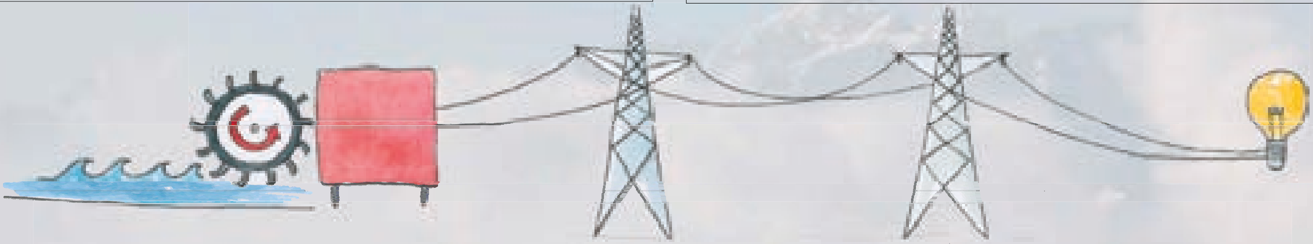
- slower driving
- less lighting
- less heating and air-conditioning

Električna energija

Electricity

Električna energija je zelo uporabna vrsta energije, ker jo enostavno prenašamo na velike razdalje in pretvarjamo v druge vrste energije za uporabo doma in v industriji.

Electricity is a very versatile kind of energy because it can be easily transmitted over great distances and transformed into other kinds of energy used in households and industry.

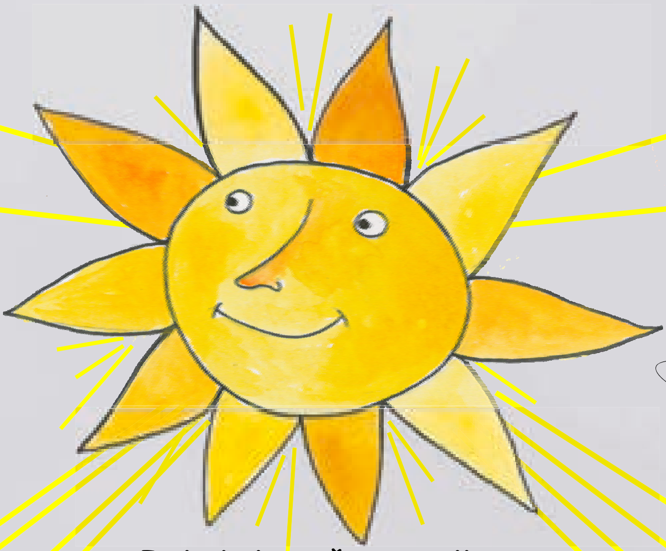


V elektrarnah proizvajamo električno energijo iz primarnih virov energije.

Electricity is generated in power plants from primary energy sources.

Glavni primarni viri energije so:

The main primary energy sources are:



Fosilni viri (premog, nafta, zemeljski plin)

Vodni viri

Jedrska energija (iz jedra atoma)

Fossil fuels (coal, oil, natural gas)

Hydroelectric

Nuclear energy (from the atomic nucleus)

Izvirajo iz sončne energije

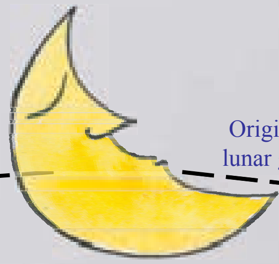
Originating from the solar energy

Alternativni viri energije (v svetu približno 2 %):

- energija vetra
- biomasa
- sončne celice
- morski valovi
- plimovanje
- geotermalna energija

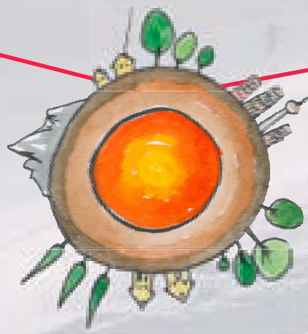
Alternative energy sources (world total about 2%):

- Wind energy
- Biomass
- Photovoltaics
- Wave energy
- Tidal power
- Geothermal power



Izvira iz Lunine gravitacije

Originates from lunar gravitation

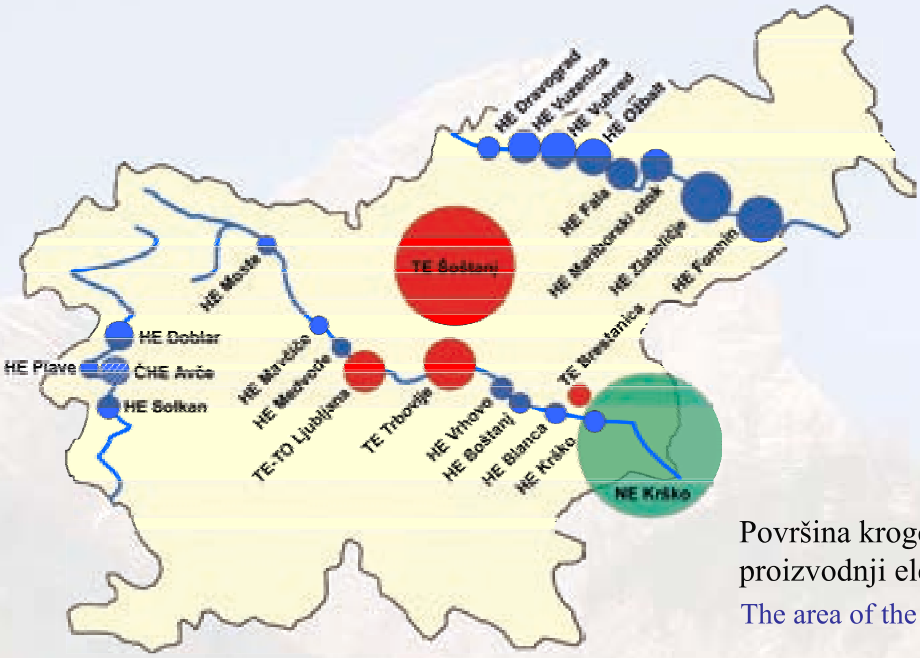


Izvira iz vroče notranjosti Zemlje

Originates from the Earth's hot interior

Proizvodnja elektrike v Sloveniji

Electrical Power Generation in Slovenia



NE Krško
Krško NPP

Termoelektrarne / / TE
Fossil fuel power plants

Hidroelektrarne / / HE
Hydroelectric power plants

Površina krogca ustreza letni proizvodnji elektrarne

The area of the circle corresponds to the annual production

Elektrarne v Sloveniji

Power Plants in Slovenia

	Moč / Power (MW)	Letna proizvodnja / Yearly production (GWh)
NE Krško	696	5680
TE Šoštanj	687	3820
TE Trbovlje	168	600
TE Brestanica	297	20
TE-TO Ljubljana	112	390
soproizvodnja, bioplinarne, ...	60	250
SKUPAJ TE / TOTAL TE	1324	5080
HE Dravograd	26	140
HE Vuzenica	56	250
HE Vuhred	72	300
HE Ožbalt	73	300
HE Fala	58	260
HE Mariborski otok	60	270
HE Zlatoličje	120	580
HE Formin	116	550
HE NA DRAVI	581	2650
HE Doblar	70	200
HE Plave	34	120
ČHE Avče	180	-130
HE Solkan	32	110
HE NA SOČI	316	300
HE Moste	21	60
HE Mavčiče	38	60
HE Medvode	25	70
HE Vrhovo	34	120
HE Boštanj	34	120
HE Blanca	42	140
HE Krško	39	140
HE NA SAVI	233	710
male HE	160	380
SKUPAJ HE / TOTAL HE	1290	4040
Sončne elektrarne (SE) / Solar plants	190	200
ELEKTRARNE SKUPAJ / TOTAL	3500	15000

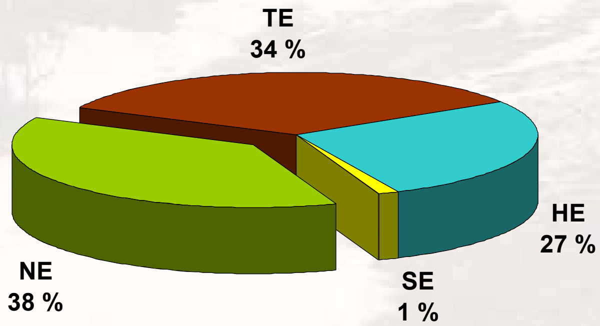
Deleži moči in proizvedene energije

Power and Energy Shares

Povprečna letna proizvodnja energije

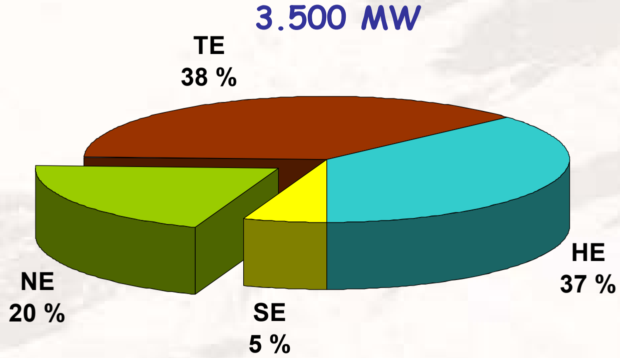
Annual average energy production

15.000 GWh



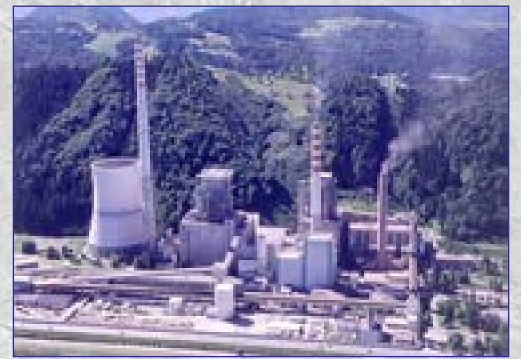
Moč elektrarn – Installed power

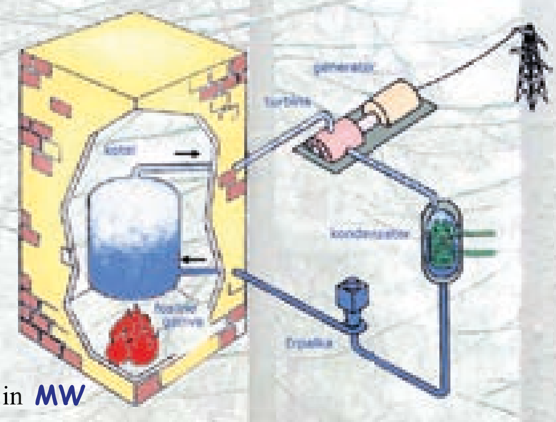
3.500 MW



Termoelektrarne

Fossil Fuel Power Plants





[1]Total power in **MW**

[2]Production in **GWh** for year 2011

TERMOELEKTRARNA ŠOŠTANJ

5 blokov skupne moči **687 MW**[1].

V letu 2012 je proizvedla **3687 GWh** električne energije[2].

TERMOELEKTRARNA TRBOVLJE

3 bloki skupne moči **168 MW**[1].

V letu 2012 je proizvedla **572 GWh** električne energije[2].

TERMOELEKTRARNA BRESTANICA

5 plinskih turbin skupne moči **297 MW**[1].

V letu 2012 je proizvedla **11 GWh** električne energije[2].

TERMOELEKTRARNA LJUBLJANA

Kombinacija toplarne in elektrarne moči **124 MW**[1].

V letu 2012 je proizvedla **372 GWh** električne energije[2].

Combination of district heating and electrical energy production.

SOPROIZVODNJA TOPLOTE IN ELEKTRIKE

V nekaj slovenskih podjetjih imajo manjše elektrarne, ki poleg toplote za proizvodni proces proizvajajo tudi električno energijo (soproizvodnja). To je najbolj učinkovit način izrabe goriv.

Cogeneration of heat and electricity

Small power plants are installed in several industrial facilities, which in addition to producing heat needed for industrial processes, also generate electrical energy. This is the most effective utilization of fossil fuels.

Gradnja novih termoelektrarn je vprašljiva zaradi obremenitve okolja s CO_2.

An increase in fossil fuel power plants would increase releases of CO_2.

Obnovljivi viri energije

Renewable Energy Sources

HE Mariborski otok

Reka Drava River Drava

[1]Skupna moč elektrarn je **584 MW**.

[2]V letu 2012 so proizvedle **2627 GWh** električne energije.

[1]Total power in **MW**

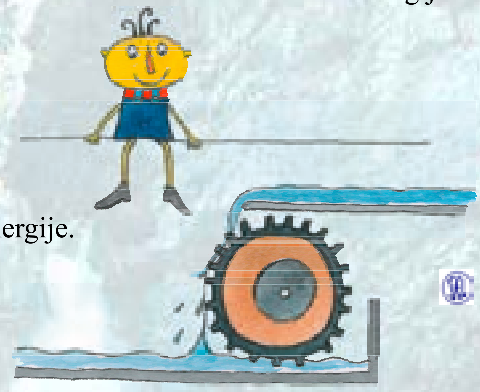
[2]Production in **GWh** for year 2011

HE Moste

Reka Sava River Sava

[1]Skupna moč elektrarn je **233 MW**.

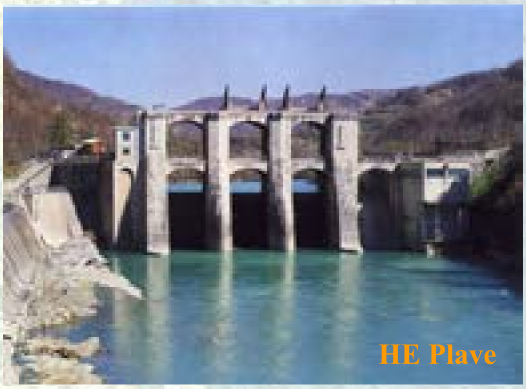
[2]V letu 2012 so proizvedle **528 GWh** električne energije.



Reka Soča River Soča

[1]Skupna moč elektrarn je **342 MW**.

[2]V letu 2011 so proizvedle **574 GWh** električne energije.



HE Plave

Prva vetrna elektrarna z močjo 2 MW stoji v bližini Senožeč.

The first wind turbine in Slovenia, with 2 MW power, is located near Senožeče.

Bogate subvencije so zelo pospešile gradnjo fotonapetostnih sončnih elektrarn.

Substantial subsidies have resulted in significant growth of photovoltaic solar power plants.

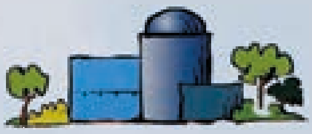
[1]Konec leta 2012 je njihova moč znašala **199 MW**.
[2]Proizvedle so **121 GWh** električne energije.

Prispevek obnovljivih virov energije, razen vodne energije, znaša v svetu okrog 2 %, v EU 2 %, v posameznih državah presega 15 %.

The contribution of renewable sources other than hydroelectric power in the world is about 2%, in the EU 2%, in some countries it exceeds 15%.

Jedrska elektrarna Krško

Krško Nuclear Power Plant



Jedrska elektrarna Krško stoji v Sloveniji ob Savi 2 km od mesta Krško in je v skupni lasti Republike Slovenije in Republike Hrvaške (50/50).

Krško NPP is located in Slovenia on the river Sava 2 km from the town of Krško, and is owned jointly by the Republic of Slovenia and the Republic of Croatia (50/50).

[2]V letu 2012 je proizvedla **5902 GWh** električne energije.

Cena elektrike iz jedrske elektrarne Krško je nižja kot iz večine drugih elektrarn v Sloveniji.

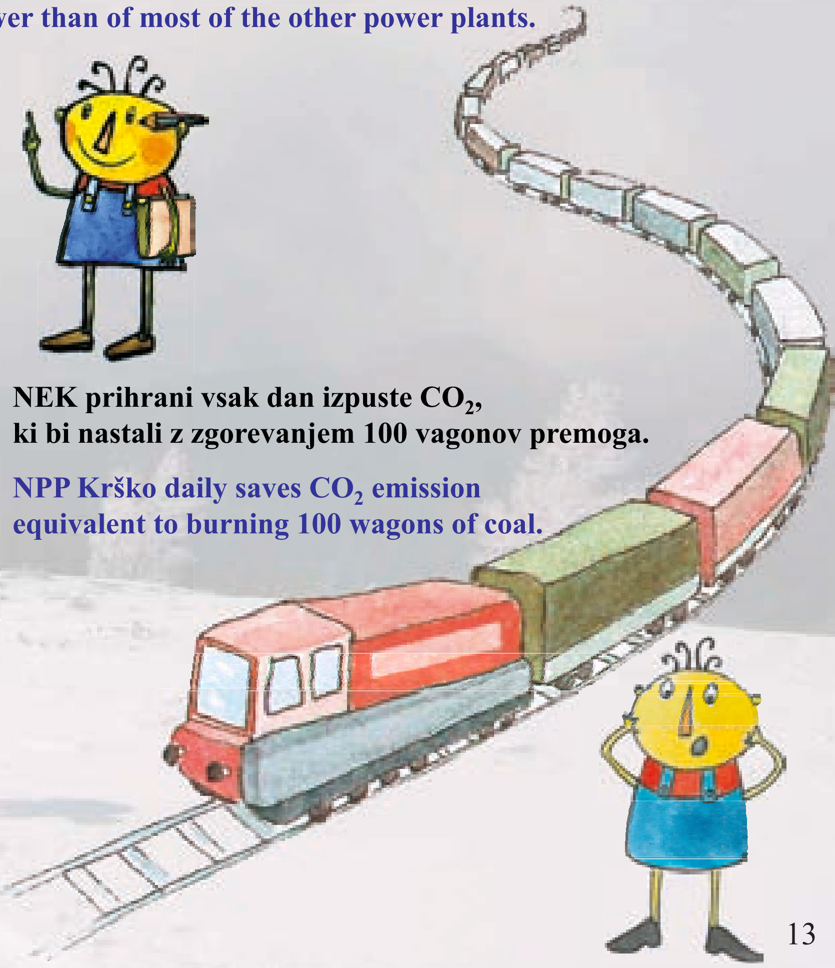
The price of electricity from Krško NPP is lower than of most of the other power plants.

Glavni podatki — Key Data

moč elektrarne electrical power	696 MW
toplotna moč reaktorja reactor thermal power	1994 MW
tlačnovodni reaktor pressurized water reactor	
tlak primarne vode primary pressure	155 bar
tlak pare pred turbino turbine steam pressure	60 bar
pretok pare skozi turbino turbine steam flow	1030 kg/s
hlajenje kondenzatorja condenser cooling flow	25 m³/s (Sava)
začetek obratovanja start of operation	1983
projektirana obratovalna doba (let) design lifetime (yrs)	40

NEK prihrani vsak dan izpuste CO_2, ki bi nastali z zgorevanjem 100 vagonov premoga.

NPP Krško daily saves CO_2 emission equivalent to burning 100 wagons of coal.

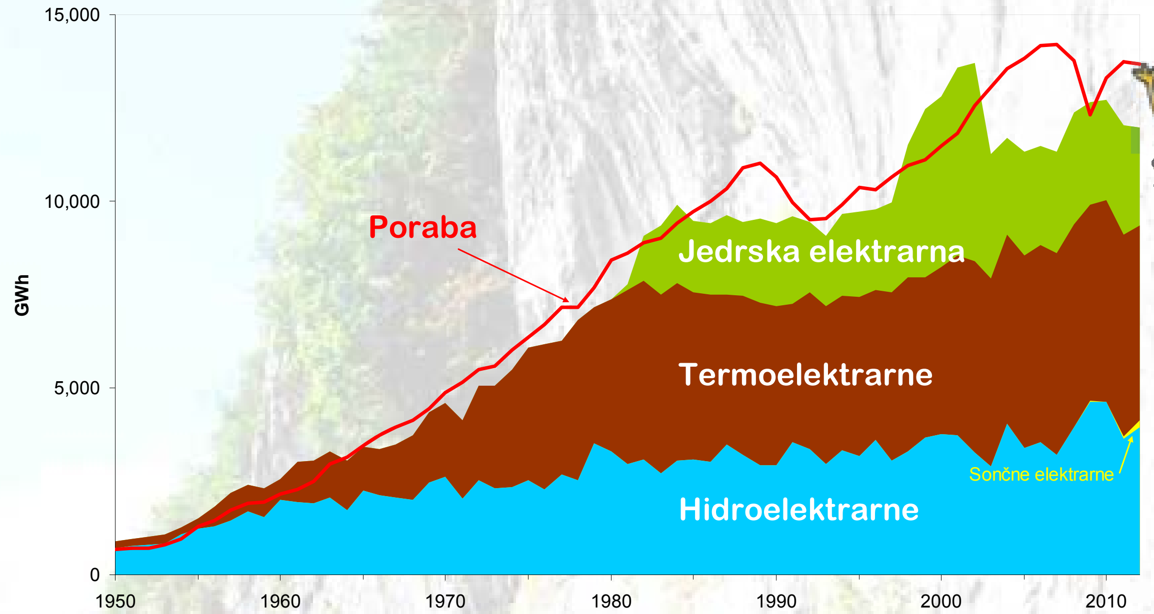


Poraba elektrike v Sloveniji

Electricity Consumption in Slovenia

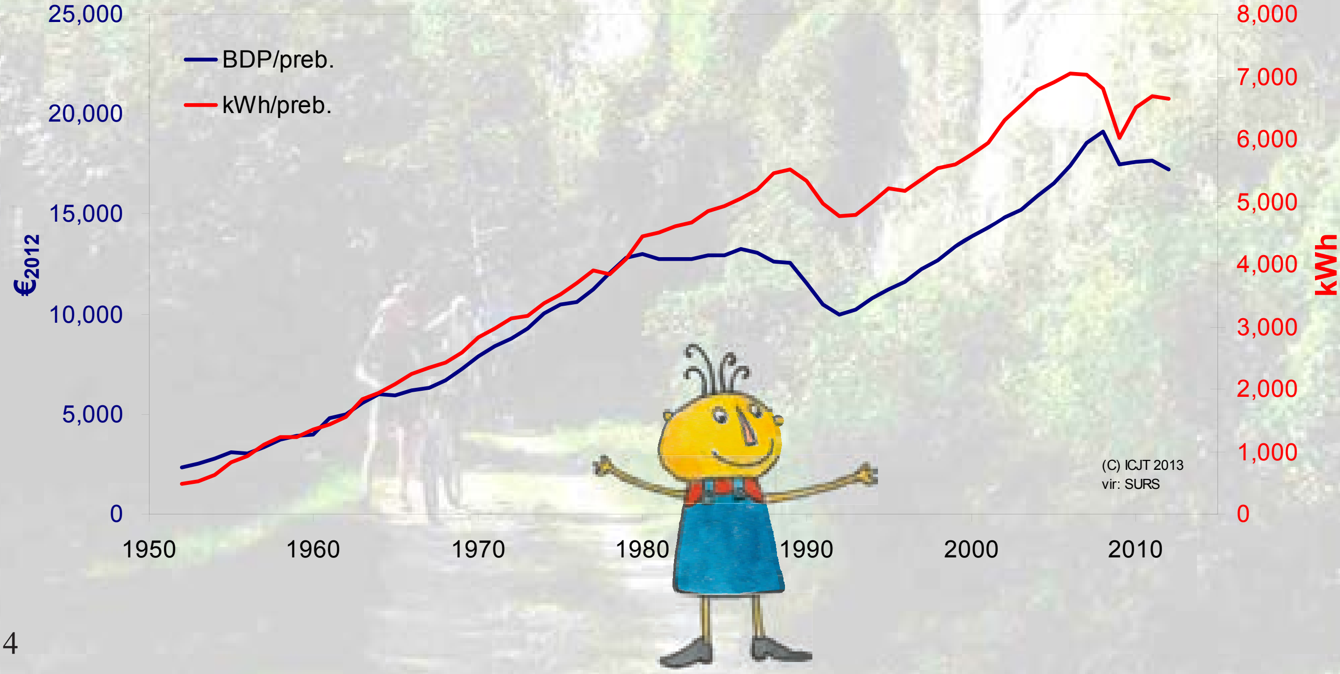
Viri električne energije v Sloveniji ne pokrivajo naraščajoče porabe.

The sources of electrical energy in Slovenia are not sufficient to cover the growing consumption.



Krivulji porabe električne energije in družbenega proizvoda na prebivalca kažeta enako rast.

The curves of electrical energy consumption and gross national product per capita show the same trend.



Učinek tople grede

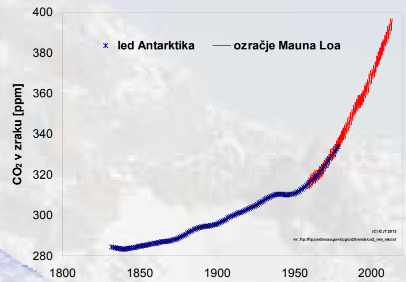
The Greenhouse Effect

Ozračje prepušča toploto, ki jo seva Sonce, in zadrži večji del toplote, ki jo seva Zemlja. Ima torej podobno vlogo kot stekleni rastlinjak ali **topla greda**.

The Earth`s atmosphere is transparent to the heat radiated by the Sun, but it reflects a major part of the heat radiated by the Earth. The atmosphere therefore acts as a **greenhouse**.

K učinku tople grede največ prispevajo ogljikov dioksid (CO_2), vodna para, metan in nekateri drugi plini.

Carbon dioxide (CO_2), water vapour, methane and some other gases are the major contributors to the greenhouse effect.



Koncentracija CO_2 v ozračju je v 50 letih narasla za 25 %.

The concentration of CO_2 in the atmosphere has increased by 25% over the last 50 years.

Pri **zgorevanju fosilnih goriv** nastaja ogljikov dioksid, ki se nabira v ozračju poleg naravno prisotnega CO_2. Zaradi povečevanja njegove koncentracije ozračje zadrži več toplote in povprečna **temperatura raste**.

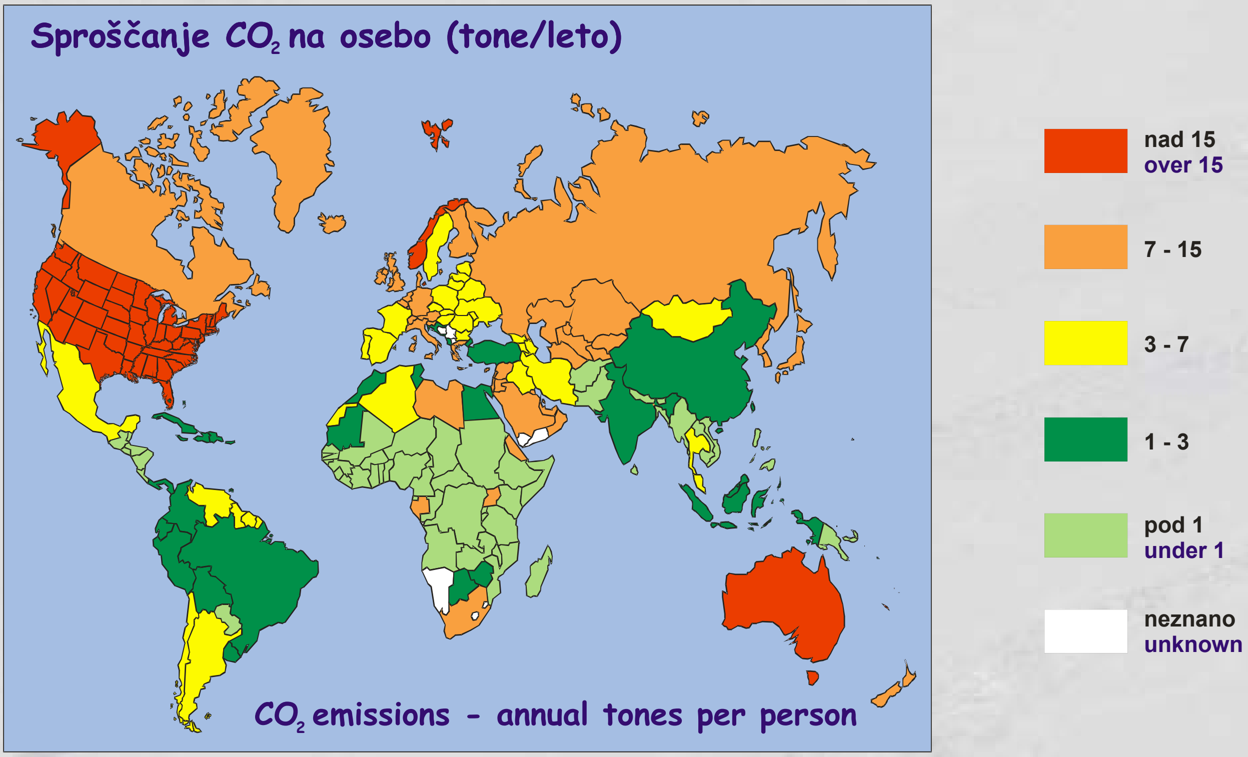
The burning of fossil fuels produces carbon dioxide, which accumulates in the atmosphere in addition to CO_2 naturally present. The increase of its concentration causes an increase in the temperature.

Sproščanje CO_2 zaradi človekovih dejavnosti

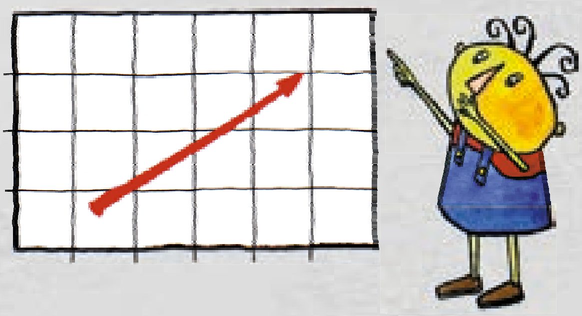
CO_2 Release Resulting from Human Activities

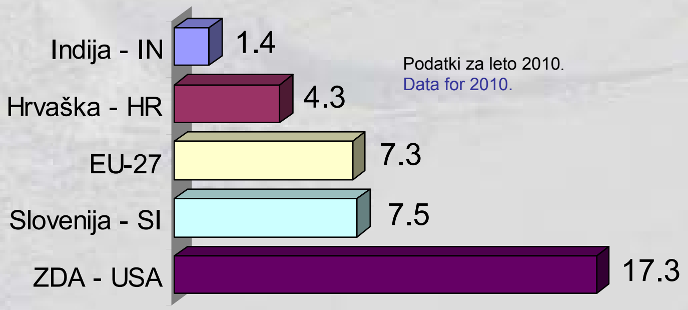
Letno sproščanje CO_2 na prebivalca je pokazatelj potratnosti pri uporabi fosilnih goriv.

The yearly release of CO_2 per capita indicates the consumption of fossil fuels.



Sproščanje CO_2 v ozračje se bo z naraščanjem prebivalstva ter industrializacijo držav v razvoju zanesljivo še povečalo, če ne bomo izvajali ustreznih ukrepov v svetovnem merilu.





Nekaj tipičnih primerov sproščanja (tone CO_2 na prebivalca)

Some typical examples of emission (in tones of CO_2 per capita)

If no appropriate measures are implemented, CO_2 releases into the atmosphere will increase due to world industrialization and increases in world population.

Posledice ogrevanja ozračja
Consequences of Global Warming

V zadnjem stoletju se je podnebje otoplilo za 0,5 °C. Če bi se koncentracija CO_2 podvojila, bi se temperatura povišala za 2 do 5 °C. Pri enaki porabi fosilnih goriv se bo to zgodilo v petdesetih letih.

The atmosphere has warmed up by 0.5 °C over the last century. Doubling the concentration of CO_2 would increase the average temperature by 2 to 5 °C. If the rate of consumption of fossil fuel remains the same, this increase will occur within 50 years.

Posledica bi bile hude klimatske spremembe:
Global warming would induce severe climate changes:

Širitev toplih podnebnih pasov ter selitev rastlinskih in živalskih vrst.

A broadening of warm climate zones and migration of plant and animal species.

Povečanje količin padavin in prerazporeditev padavinskih območij.

An increase in precipitation, and relocation of precipitation zones.

- Dvig morske gladine zaradi taljenja polarnega ledu in toplotnega raztezanja oceanov.
- Burnejše vremensko dogajanje po celem svetu.

- A rise in sea level due to melting of polar ice and the thermal expansion of ocean water.
- More frequent stormy weather throughout the world.

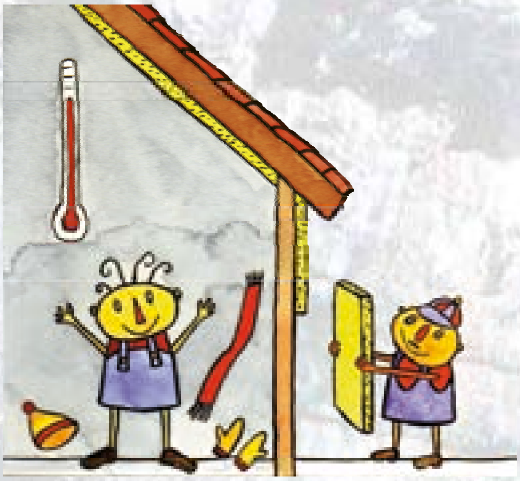
Ukrepi za zmanjšanje sproščanja CO_2
Measures for Reducing CO_2 Emissions

Ker je CO_2 svetovni problem, bodo lahko uspešni le ukrepi v svetovnem merilu. Tehnično so izvedljivi:

Only global measures can be effective, because CO_2 is a global problem. Technically feasible measures include:

1. **Nadomeščanje premoga** z zemeljskim plinom, ki vsebuje manj ogljika.

1. **Replacement of coal** with natural gas, which contains less carbon.



2. **Zmanjšanje porabe fosilnih goriv** z racionalizacijo in varčevanjem na vseh področjih.

2. **A reduction of fossil fuel consumption** through rationalization.

3. Večja uporaba **obnovljivih virov energije in jedrske energije.**

3. Increased usage of **renewable sources of energy and nuclear power.**

Če bi želeli ohraniti sedanje podnebje, bi smel povprečen Zemljan leta 2050 sproščati le približno eno tono CO_2 na leto.

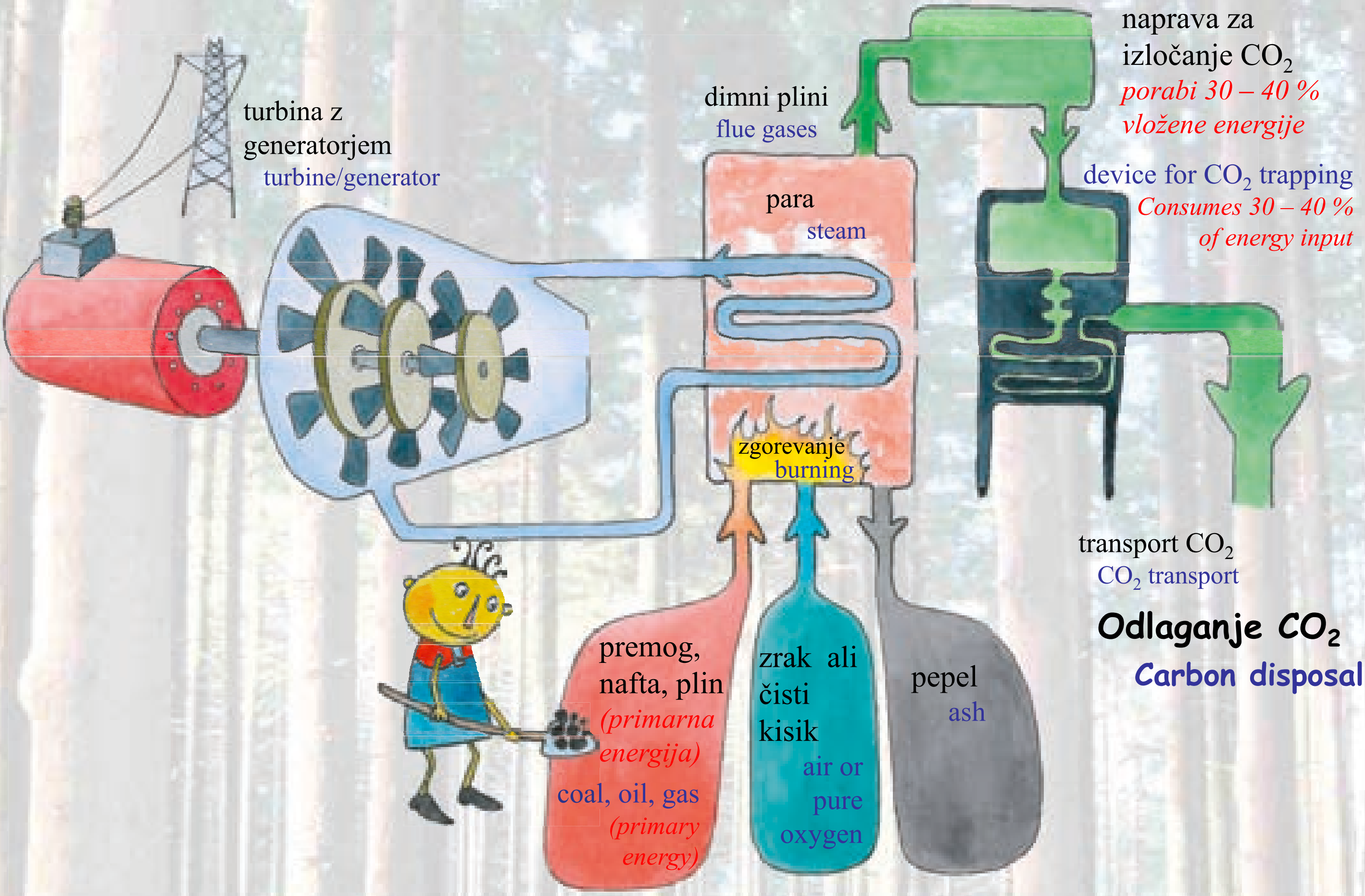
If we want to preserve the world's present climate, the average release of CO_2 per person in the year 2050 would need to be limited to one ton per year.

Zajemanje in skladiščenje CO_2

Carbon Capture and Sequestration

Zajemanje in skladiščenje CO_2 je zamisel za dolgoročno shranjevanje ogljikovega dioksida v biosfero, pod zemljo ali v oceane namesto izpuščanja v ozračje.

Carbon Capture and Sequestration is a concept for trapping and long-term storage of carbon in the biosphere, underground, or in the oceans instead of emitting carbon dioxide into the atmosphere.



Odlaganje CO_2

Carbon disposal

Prednost

- Uporaba fosilnih goriv brez izpusta CO_2

Advantage:

- CO_2−free burning of fossil fuels

Pomanjkljivosti

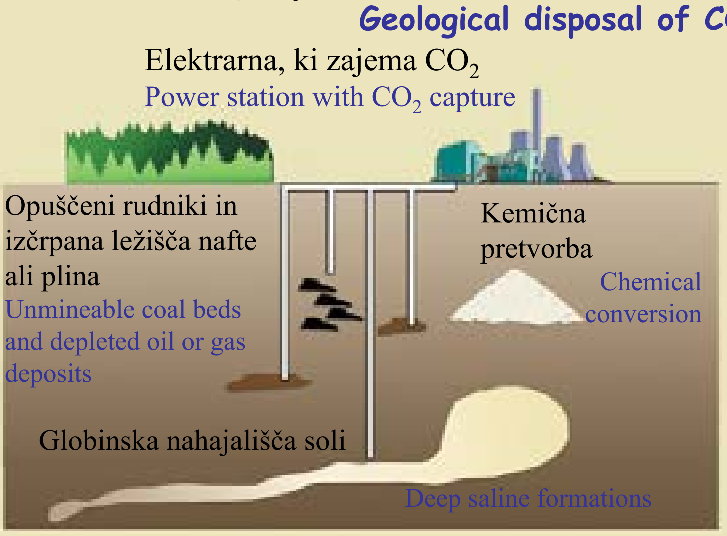
- Tehnologija šele v razvoju
- Velike izgube primarne energije
- Negotovost odlaganja CO_2

Disadvantages:

- Technology still under development
- Big losses of primary energy
- Uncertainty of CO_2 disposal

Geološko odlaganje CO_2

Geological disposal of CO_2



Vodikova tehnologija

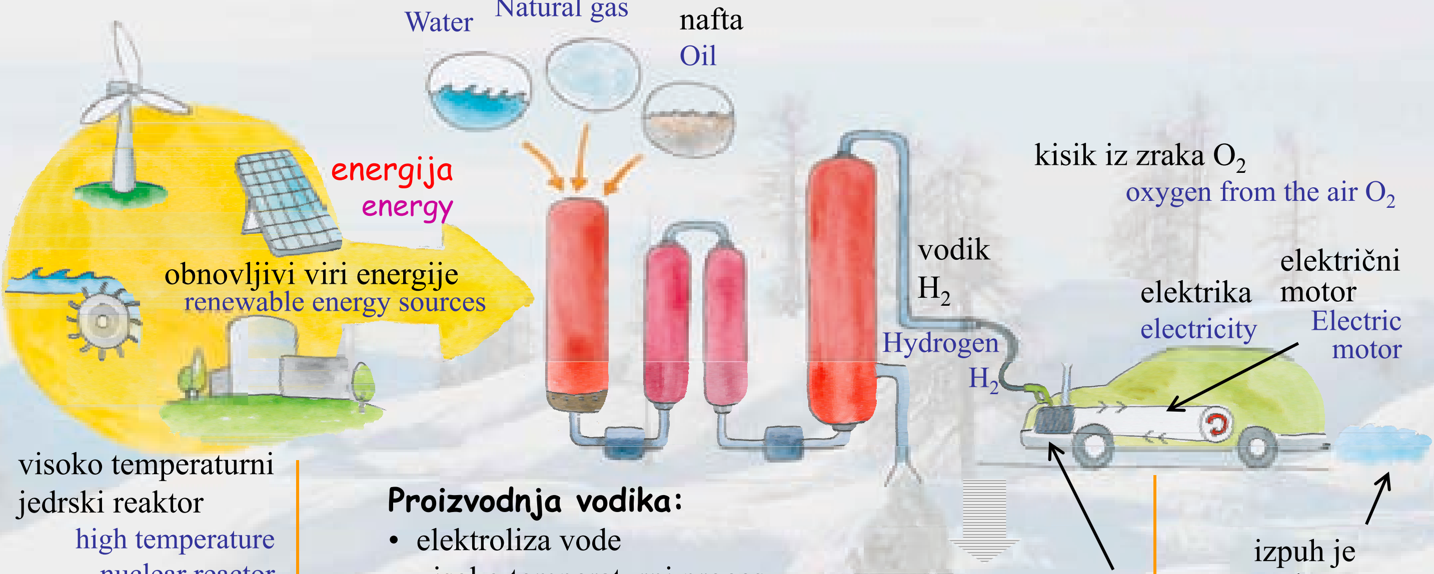
Hydrogen Technology

Vodik v **gorivni celici** reagira s kisikom iz zraka, proizvedena elektrika poganja električni motor za pogon vozila brez izpustov ogljikovega dioksida.

Hydrogen in **a fuel cell** reacts with oxygen from the air, producing electricity for powering cars without CO_2 emissions.

Na Zemlji **ni prostega vodika**. Vodik **ni** primarni vir energije, ampak samo sredstvo za skladiščenje in prenos energije.

There is **no free hydrogen** on Earth. Hydrogen is **not** a primary energy source, it is just an energy storage and carrier medium.



Proizvodnja vodika:
- elektroliza vode
- visoko temperaturni proces
- kemični proces

Hydrogen production plant:
- Electrolysis of water
- High temperature process
- Chemical process

samo ~25 % vložene energije je elektrika

only ~25 % of the energy input is obtained as electricity

Prednost: ni izpustov CO_2, **vendar samo**, če sta primarni vir energije in vir vodika brez ogljika.
Pomanjkljivosti:
- slab izkoristek (električne energije iz gorivne celice je samo 25 % primarne energije),
- zahtevno ravnanje z vodikom (skladiščenje pri zelo visokih tlakih ali zelo nizki temperaturi)

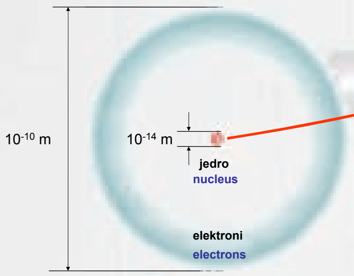
Advantage: no CO_2 emission, **but only if** the primary source of energy and the source of hydrogen are carbon free.
Disadvantages:
- Low efficiency (electrical energy from the fuel cell is just 25% of primary energy input),
- Hydrogen storage at very high pressures or very low temperatures

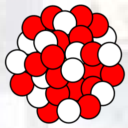
Zgradba snovi

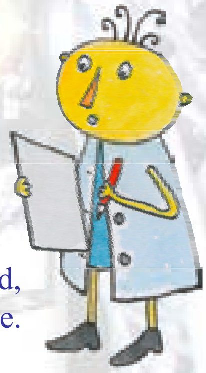
The Structure of Matter

Atom je osnovni gradnik snovi.
Sestavljen je iz **jedra** in **elektronov**.
The **Atom** is the basic constituent of matter.
It consists of a **nucleus** and **electrons**.

Jedro je sestavljeno iz protonov in nevtronov.
The **Nucleus** consists of protons and neutrons.







Protoni imajo pozitiven naboj,
nevtroni so brez naboja.
Protons are positively charged,
neutrons have no charge.

Elektroni so razpršeni okrog jedra in imajo negativen naboj.
Electrons are dispersed around the nucleus and are negatively charged.

V nevtralnem atomu je število protonov in elektronov enako.
In a neutral atom there is an equal number of protons and electrons.

Kemične lastnosti atoma so določene s številom elektronov (in protonov).
Chemical properties of the atom are determined by the number of electrons (and protons).

Označitev atomskega jedra
Notation of the atomic nucleus

$^{4}_{2}\mathrm{He}$

Masno število označuje skupno število protonov in nevtronov v jedru.
The mass number denotes the total number of protons and neutrons in the nucleus.

Vrstno število nam pove število protonov v jedru.
The atomic number denotes the number of protons in the nucleus.

Kemični element je snov, ki je sestavljena iz atomov z istim vrstnim številom.
A **chemical element** is a substance which consists of atoms with the same atomic number.

Poznamo **več kot 100** kemičnih elementov.
More than 100 chemical elements are known.

Izotopi so atomi istega kemičnega elementa, ki se med seboj razlikujejo po številu nevtronov v jedru.
Isotopes are atoms of the same chemical element which differ in the number of neutrons in the nucleus.

Vodik ima tri izotope.
Hydrogen has three isotopes.

Radioaktivnost

Radioactivity

Določena atomska jedra so nestabilna in razpadajo v stabilna jedra. Ta pojav se imenuje **radioaktivni razpad**.

Certain atomic nuclei are unstable and decay into stable nuclei. This phenomenon is known as **radioactive decay**.

nestabilno jedro / unstable nucleus — radioaktivni razpad / radioactive decay — stabilno jedro / stable nucleus

Nestabilna jedra razpadajo sama od sebe.

Unstable nuclei decay spontaneously.

Radioaktivnost je **naravni pojav**, ki je star kot vesolje. Odkrita je bila pred dobrim stoletjem.

Radioactivity is a **natural phenomenon** as old as the universe. It was discovered more than a century ago.

Pri radioaktivnem razpadu se sprošča energija, ki potuje skozi prostor v obliki valovanja ali delcev. Tej energiji pravimo **radioaktivno sevanje**.

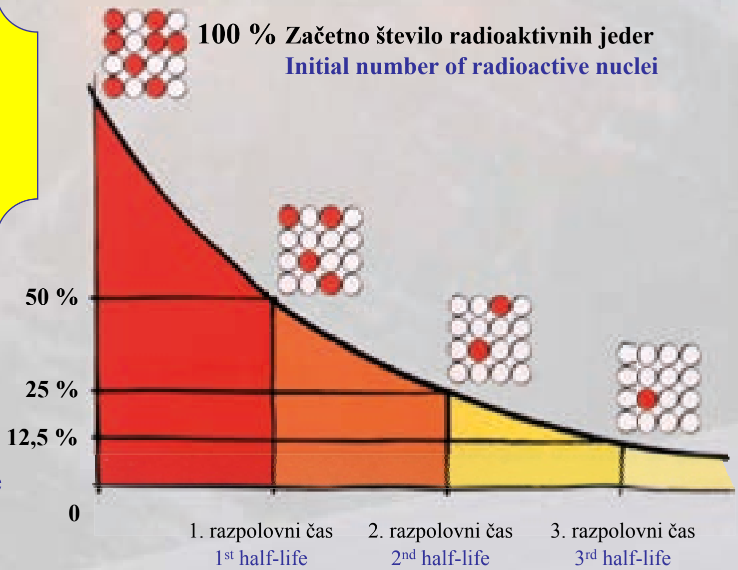
During radioactive decay, energy is released which travels through space in the form of particles or waves. The emitted energy is known as **radiation**.

Število radioaktivnih jeder s časom upada.

The number of radioactive nuclei decreases with time.

Razpolovni čas imenujemo čas, v katerem razpade polovica začetnega števila radioaktivnih jeder.

The **half-life** is the time period in which half of the initial number of radioactive nuclei decay.



Vrste sevanja

Types of Radiation

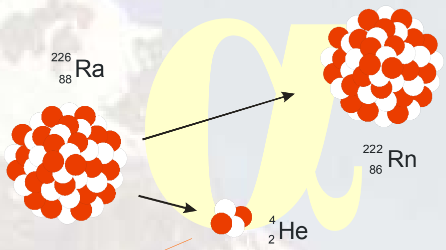
Jedra razpadajo na različne načine, zato obstajajo različne vrste radioaktivnega sevanja.

Nuclei can decay in different ways, therefore different types of radiation exist.

Sevanje alfa (alpha radiation)

Pri razpadu alfa iz radioaktivnih jeder odletijo delci alfa **– jedra helija –** 2 protona in 2 nevtrona.

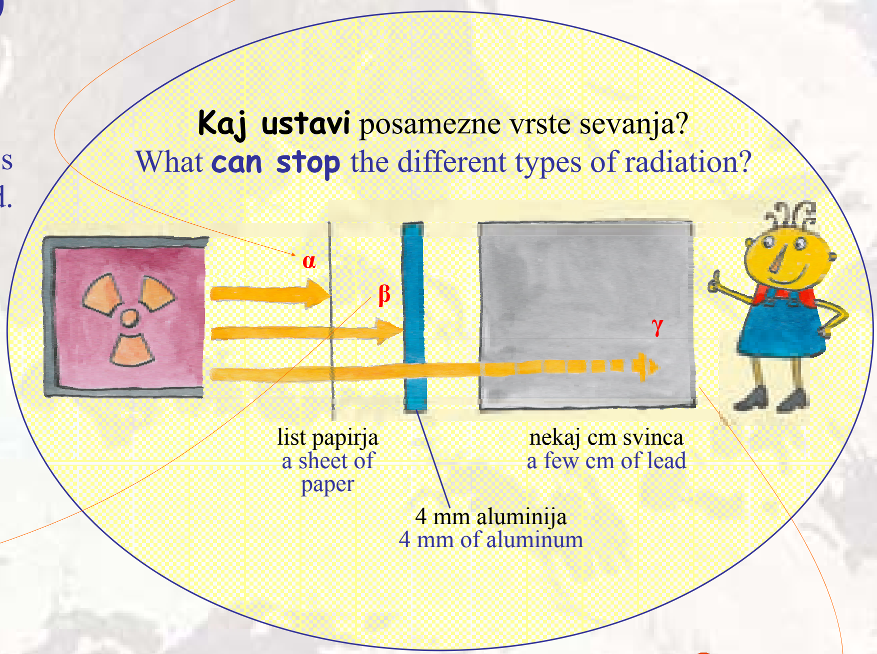
During alpha decay, alpha particles **– helium nuclei** (with 2 protons and 2 neutrons) are emitted.

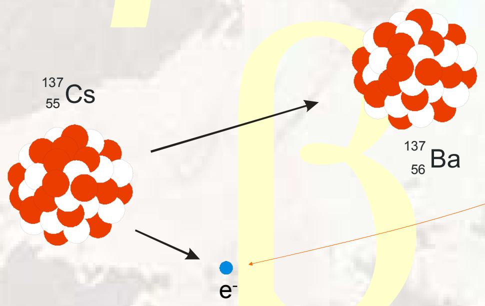


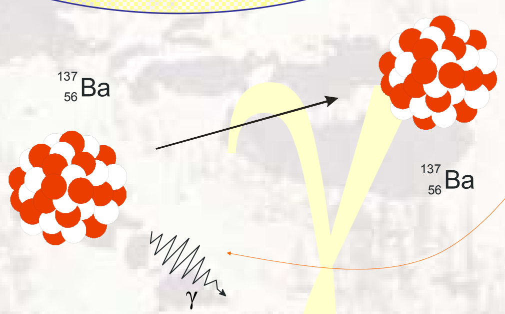
Sevanje beta (beta radiation)

Pri razpadu beta iz radioaktivnih jeder odletijo delci beta **– elektroni**.

During beta decay, beta particles (**electrons**) are emitted.







Sevanje gama (gamma radiation)

Razpad gama ponavadi sledi razpadoma alfa ali beta, ko novonastalo jedro odda odvečno energijo v obliki **elektromagnetnega valovanja – fotona**.

Gamma decay usually follows alpha or beta decay, where the daughter nucleus emits the surplus energy in the form of **electromagnetic radiation (photon)**.

Nevtronsko sevanje nastaja pri nekaterih *jedrskih reakcijah*, predvsem pri cepitvi urana v jedrskih reaktorjih.

Neutron radiation results from certain *nuclear reactions*, in particular during fission of uranium in nuclear reactors.

Merjenje radioaktivnosti

Measurement of Radioactivity

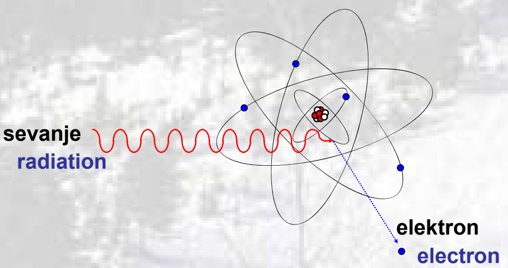
Radioaktivnega sevanja s svojimi čuti ne moremo zaznati. Odkrijemo ga lahko po raznih učinkih na atome snovi, skozi katero prehaja.

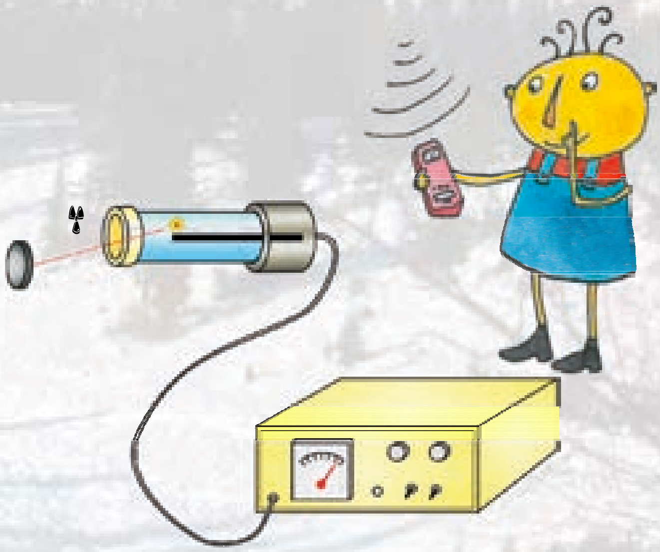
Radiation cannot be detected by our senses. However, because radiation affects the atoms through which it passes, we can easily detect it using a variety of methods.

Detektorji sevanja lahko zaznajo izredno nizke nivoje sevanja, bistveno nižje od tistih, ki so škodljivi za ljudi.

Radiation detectors can detect very low levels of radiation, substantially lower than levels harmful for humans.

Radioaktivno sevanje izbija elektrone iz atomov ob svoji poti. Ta pojav se imenuje **ionizacija**. Zato je radioaktivno sevanje tudi **ionizirajoče sevanje**.





Radiation from radioactive decay knocks out electrons from the atom. This effect is called **ionization**. Such radiation is therefore also **ionizing radiation.**

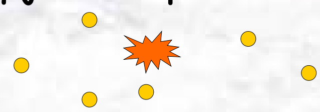
V **plinskem detektorju** sevanje ionizira plin v cevi. Nastali nabiti delci, elektroni (-) in ioni (+) omogočijo električni tok skozi cev. Jakost toka je sorazmerna sevanju. Najbolj uporabljani plinski detektor je **Geiger-Müllerjeva cev**.

In a **gas detector** the radiation ionizes the gas in a tube. The resulting charged particles, electrons (-) and ions (+), form an electric current through the tube. The strength of the current is proportional to the radiation. The most widely used gas detector is the **Geiger-Müller counter.**

Aktivnost izvora merimo v bekerelih (Bq).

The **activity** of a source is measured in Becquerels (Bq).

1 Bq je en razpad na sekundo



1 Bq is one decay per second

Dozo sevanja, ki je merilo obsevanosti človeka, merimo z enoto **sivert (Sv).** Običajno uporabljamo manjšo enoto **1mSv = 0,001 Sv.**

Radiation dose is a measure of its impact on the human body. The unit is the **sievert (Sv).** Normally a smaller unit **1 mSv = 0.001 Sv** is used.

Energija jedrskih reakcij

Energy from Nuclear Reactions

Protoni in nevtroni so v jedrih najmočneje povezani (imajo najnižjo potencialno energijo), kadar jih je v jedru okoli 60 (npr. železo ^{57}Fe).

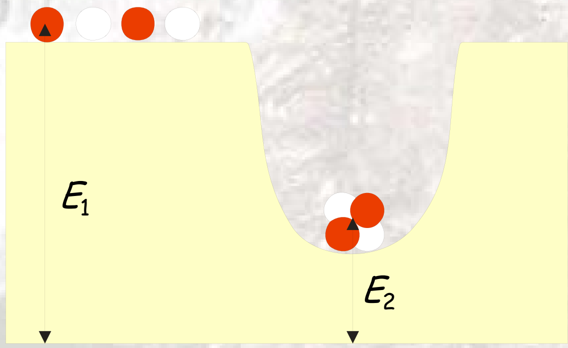
The bonds between protons and neurons in nuclei are the strongest (they have the lowest potential energy) when there are around 60 of them in a nucleus (e.g. Iron ^{57}Fe).

Dve vrsti **jedrskih reakcij** povzročita znižanje potencialne energije in s tem sproščanje energije: **zlivanje** lahkih jeder ali **fuzija** oziroma **cepitev** težkih jeder ali **fisija**.

Two types of **nuclear reactions** cause a decrease in potential energy and consequently a release of energy: **fusion** of light nuclei or **fission** of heavy nuclei.

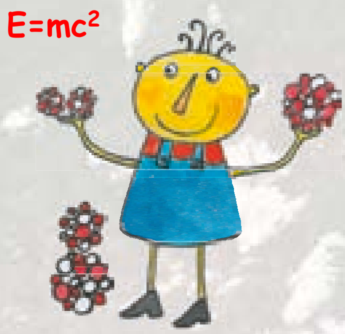
Fuzija ali zlivanje

Fusion



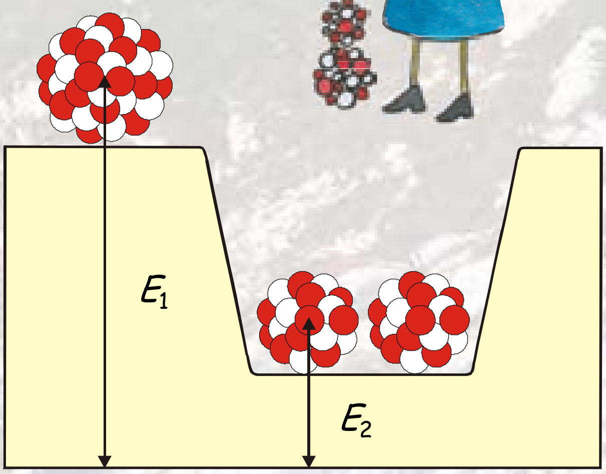
Jedro iz dveh protonov in dveh nevtronov ima manjšo potencialno energijo kot štirje nepovezani delci. Ob zlitju se sprosti energija $E_1 - E_2$.

A nucleus of two protons and two neutrons has a lower potential energy than four unbound particles. Energy $E_1 - E_2$ is released during their fusion.



Fisija ali cepitev

Fission



Dve srednje veliki jedri imata manjšo skupno potencialno energijo) kot veliko jedro. Ob cepitvi se sprosti energija $E_1 - E_2$.

Two medium sized nuclei have lower total potential energy than one large nucleus. Energy $E_1 - E_2$ is released during its fission.

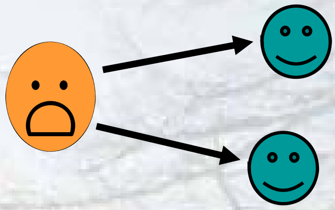
Jedrska cepitev

Nuclear Fission

Zaenkrat pridobivamo jedrsko energijo izključno na podlagi cepitve jeder.
At present, only nuclear fission is used as a source of nuclear energy.

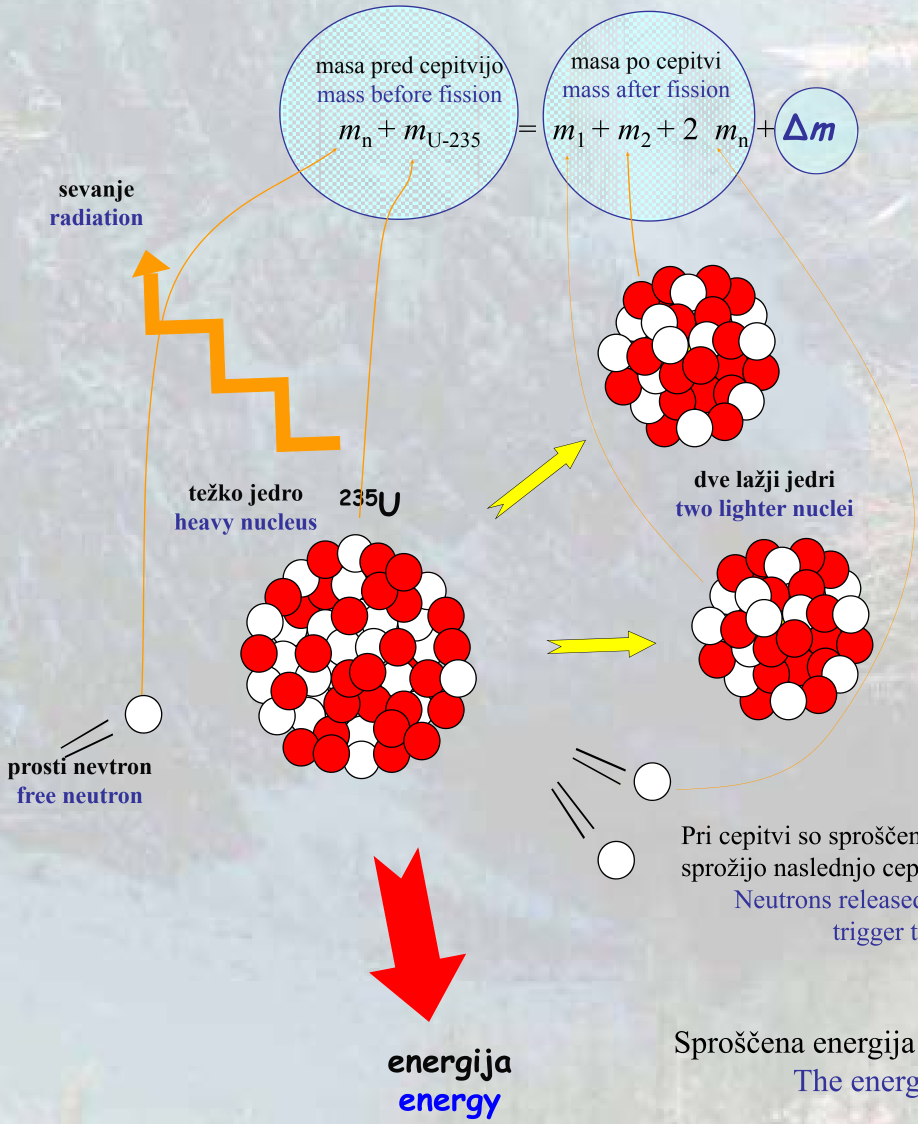
Jedra najtežjih elementov (npr. uran) se lahko **razcepijo na dve** jedri lažjih elementov.

The nuclei of the heaviest elements (e.g. uranium) can split (undergo **fission**) **into two** nuclei of lighter elements.



Cepitev spodbudimo tako, da jedra urana **obsevamo z nevtroni**.
Fission is induced by irradiation of uranium nuclei **with neutrons**.

Med cepitvijo se del mase pretvori v energijo.
During fission, some mass is converted into energy.



Nastali lažji jedri predstavljata izvor večine **radioaktivnih odpadkov**.
New light nuclei are the source of most of the **radioactive waste**.

Pri cepitvi so sproščeni nevtroni, ki sprožijo naslednjo cepitev.
Neutrons released during fission trigger the next fission.

Sproščena energija se pojavi kot **toplota**.
The energy released is converted into **heat**.

Jedrska verižna reakcija

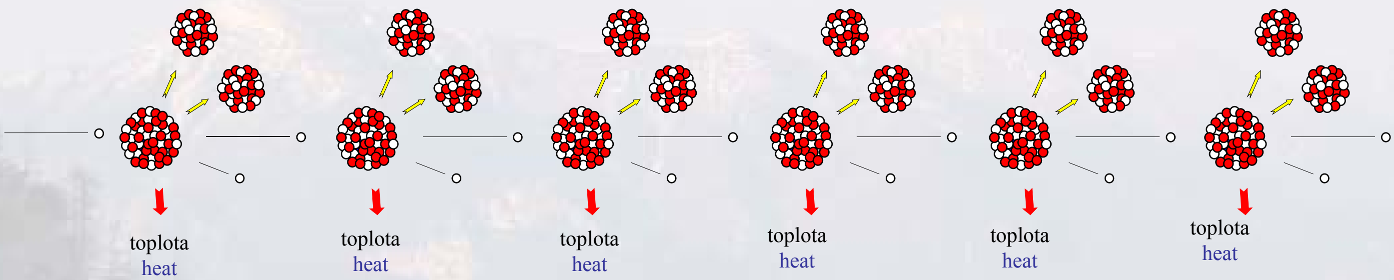
Nuclear Chain Reaction

Pri cepitvi se sproščajo **nevtroni** in **toplota**.

Neutrons and **heat** are released during fission.

Sproščeni nevtroni lahko sprožijo nove cepitve … tako steče **verižna reakcija**.

Emitted neutrons can induce new fissions ... thus a **chain reaction** is created.



Za proženje cepitve so najbolj učinkoviti **počasni** ("*termični*") **nevtroni**, medtem ko se pri cepitvi rodijo **hitri nevtroni**. Za **upočasnjevanje** nevtronov poskrbi snov iz lahkih atomov, ki se imenuje **moderator**.

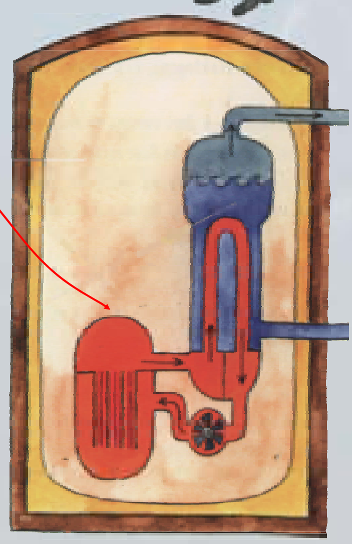
Fission is more readily induced by **slow** ("*thermal*") **neutrons**, while the neutrons released during fission are **fast neutrons**. The **slowing down** of neutrons takes place in a substance composed of light atoms, the **moderator**.

Cepitve v verižni reakciji so stalen vir **toplote**, ki jo odvaja **hladilo**.

Fissions in the chain reaction are a constant source of **heat**, which is removed by a **coolant**.

Jedrsko **verižno reakcijo** vzdržujemo v **jedrskem reaktorju**.

A nuclear **chain reaction** is maintained in a **nuclear reactor**.



<u>Reaktor vsebuje:</u>

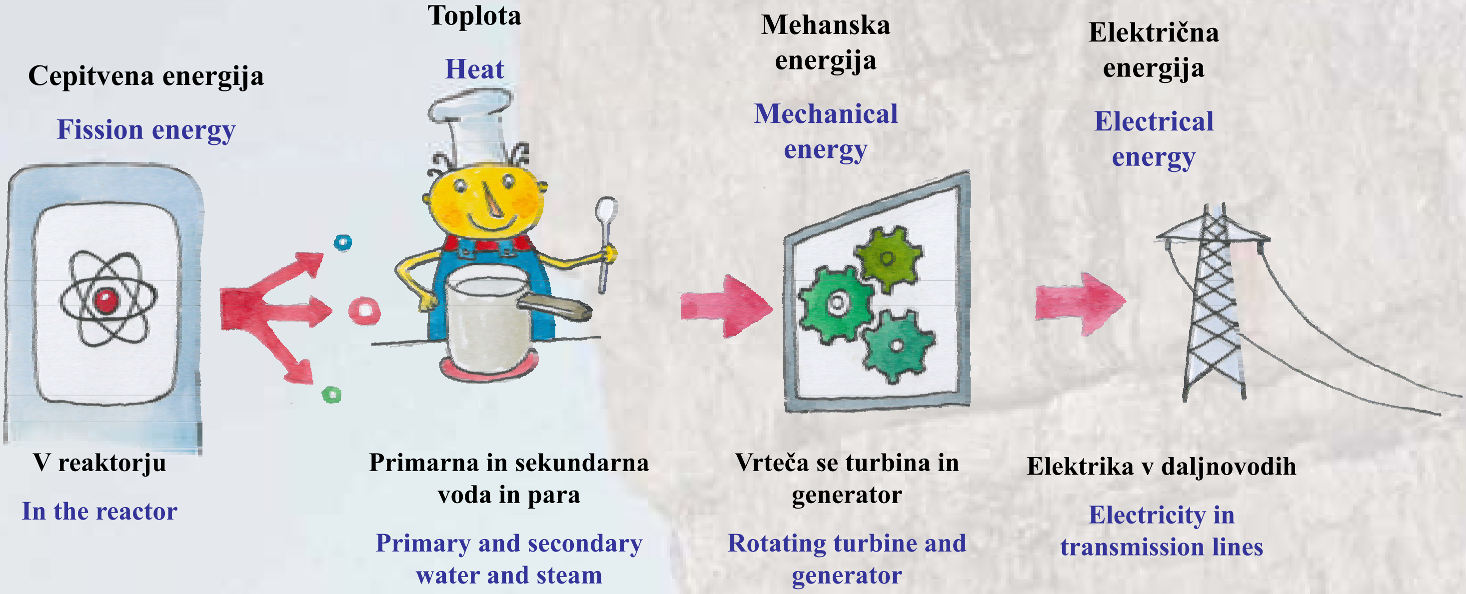
- **gorivo** (uran, običajno kot uranov dioksid)
- **moderator** (voda, težka voda ali grafit)
- **hladilo** (voda, težka voda ali plin)
- **regulacijo** (regulacijske palice ali dodatki v hladilu)
  – za nadzor poteka verižne reakcije in moči reaktorja

<u>A reactor contains:</u>

- **fuel** (uranium, usually as uranium dioxide)
- **moderator** (water, heavy water or graphite)
- **coolant** (water, heavy water or gas)
- **regulation** (control rods or additives to coolant)
  – to control the chain reaction and reactor power

Od jedrske energije do elektrike

From Nuclear Energy to Electricity

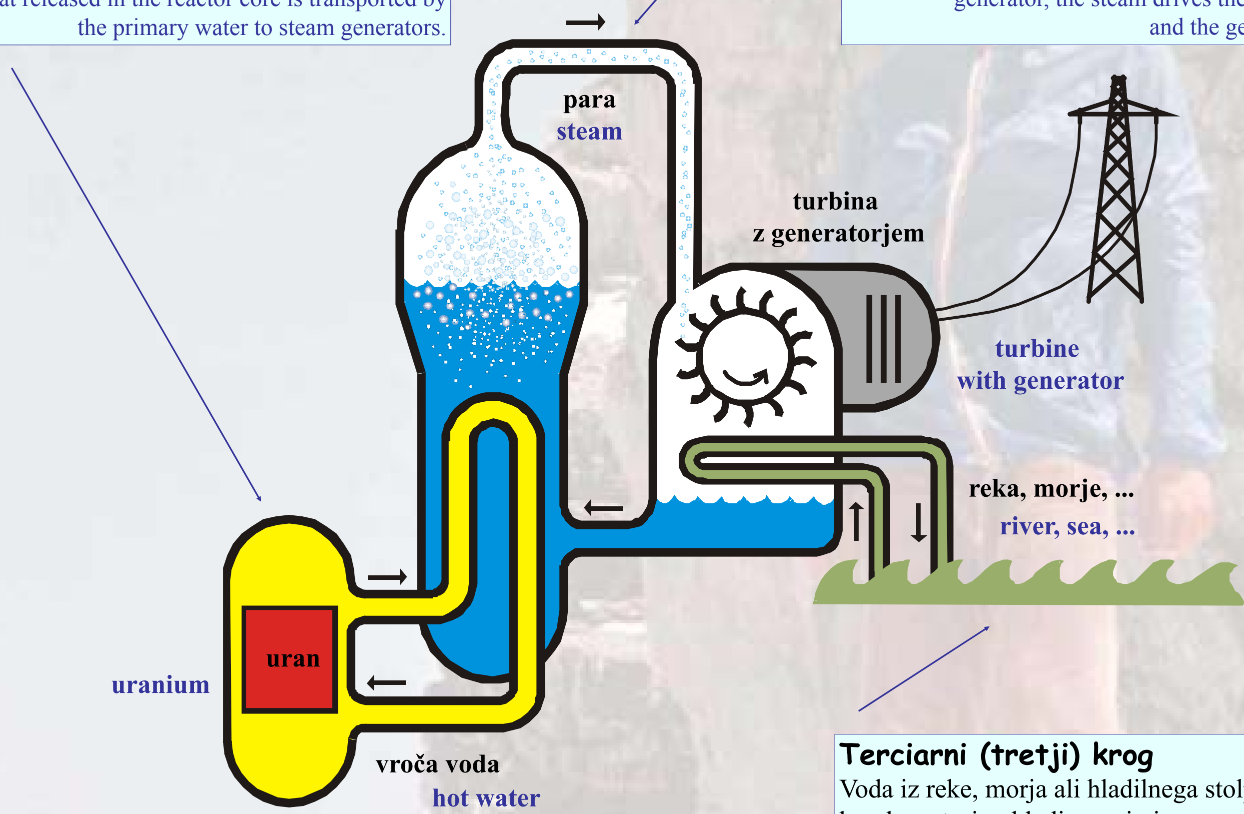


Primarni krog
V reaktorju se sprošča toplota, ki jo primarna voda v uparjalniku prenaša na sekundarno vodo.

Primary System
Heat released in the reactor core is transported by the primary water to steam generators.

Sekundarni krog
Sekundarna voda se v uparjalniku uparja, para poganja turbino in generator.

Secondary System
Secondary water is vaporized in the steam generator, the steam drives the turbine and the generator.



Terciarni (tretji) krog
Voda iz reke, morja ali hladilnega stolpa v kondenzatorju ohladi paro in jo spremeni spet v vodo, ki gre nazaj v uparjalnik.

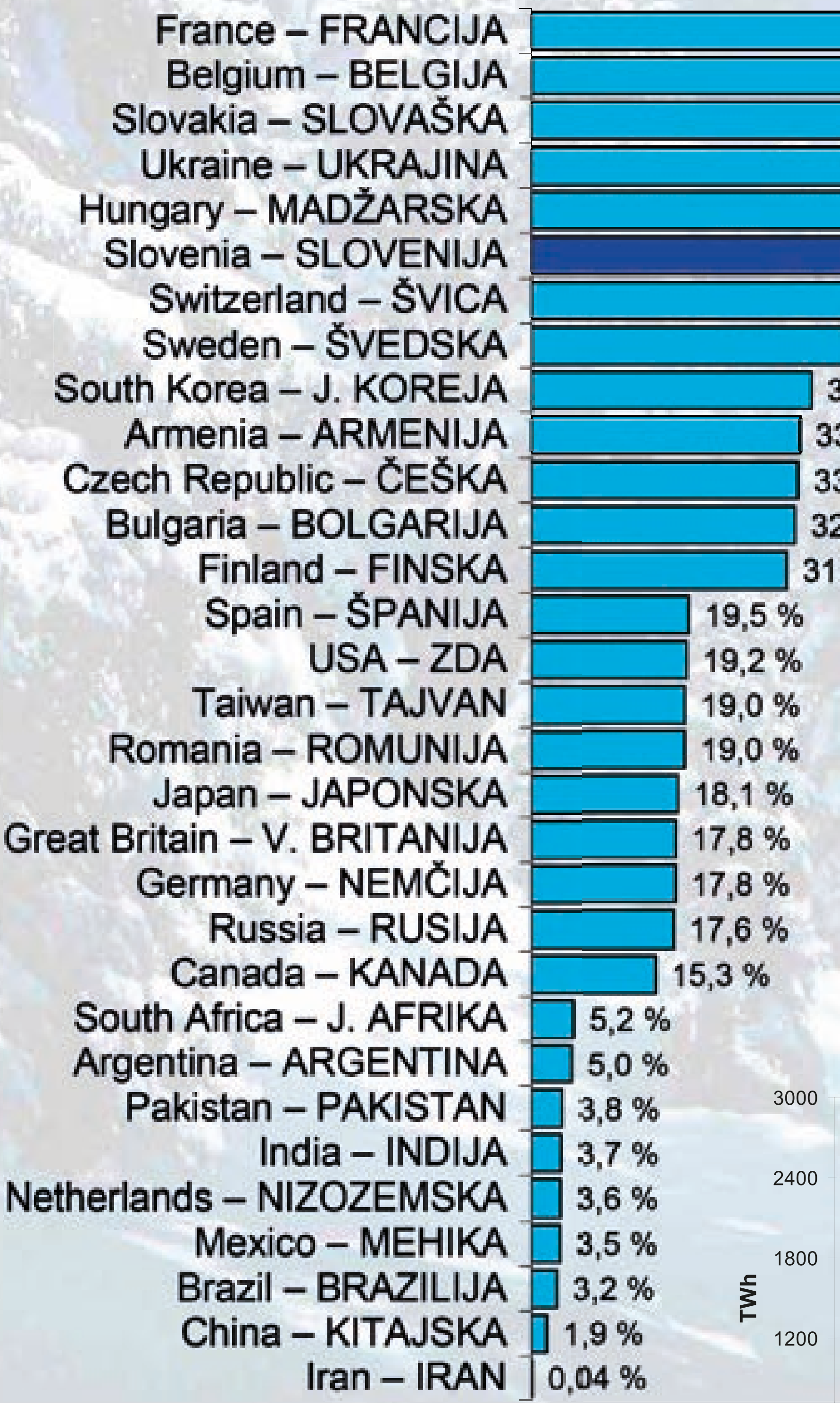
Tertiary Cycle
Water from a river, sea or cooling towers is used to condense steam back into liquid water, which is then pumped back into the steam generator.

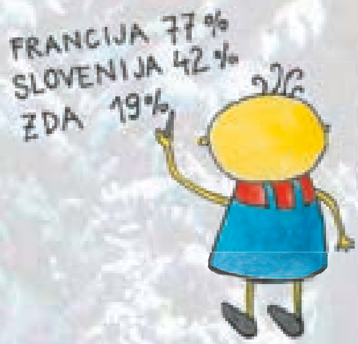
Deleži jedrske energije v proizvodnji elektrike

Nuclear Share in Electricity Generation

Jedrske elektrarne proizvedejo 12 % vse električne energije na svetu.

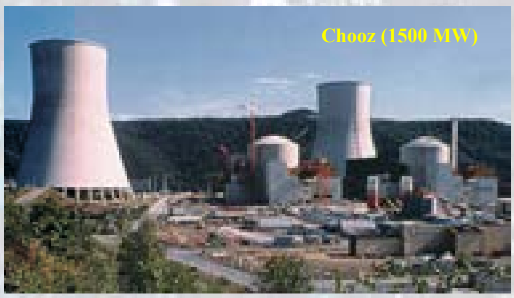
Nuclear power plants are producing 12% of the world's total electrical energy.





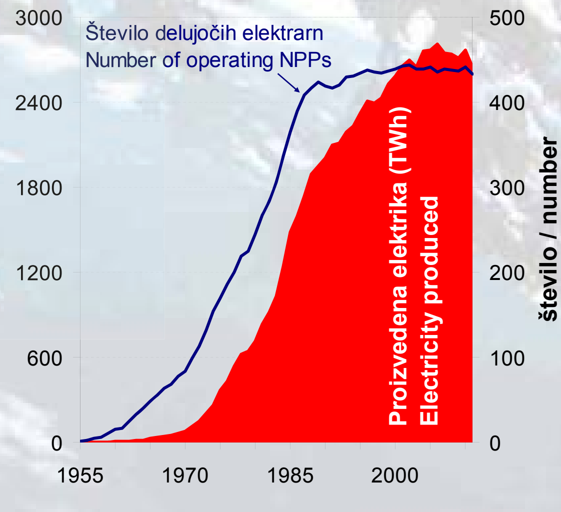
Podatki za leto 2011

Data for 2011



Najmočnejša obratujoča jedrska elektrarna je v Franciji.

The most powerful operating nuclear power plant in the world is in France.



Jedrske elektrarne v Evropi...

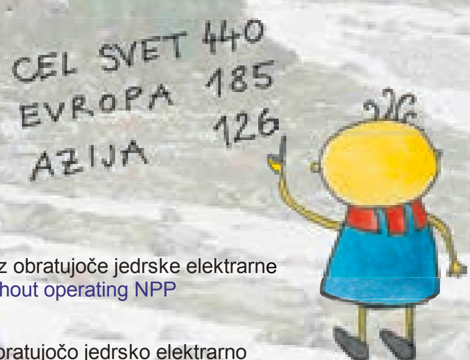
Nuclear Power Plants in Europe...

Stanje dne 31.12. 2012.
Status as of 31 December 2012.

Na eni označeni lokaciji je lahko tudi več reaktorjev.
Each indicated location can represent several reactors.

...in na drugih kontinentih

...and on Other Continents



Država brez obratujoče jedrske elektrarne
Country without operating NPP

Država z obratujočo jedrsko elektrarno
Country with operating NPP

Država z jedrsko elektrarno v gradnji
Country with NPP under construction

Stanje dne 31.12. 2012.
Status as of 31 December 2012.

Na eni označeni lokaciji je lahko tudi več reaktorjev.
Each indicated location can represent several reactors.

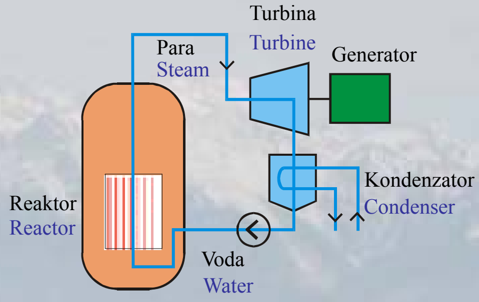
Vrste jedrskih elektrarn

Types of Nuclear Power Plants

Vrelna jedrska elektrarna
BWR (Boiling Water Reactor)

Moderirana in hlajena je z navadno vodo. Voda **se uparja v reaktorju**, para poganja turbino.

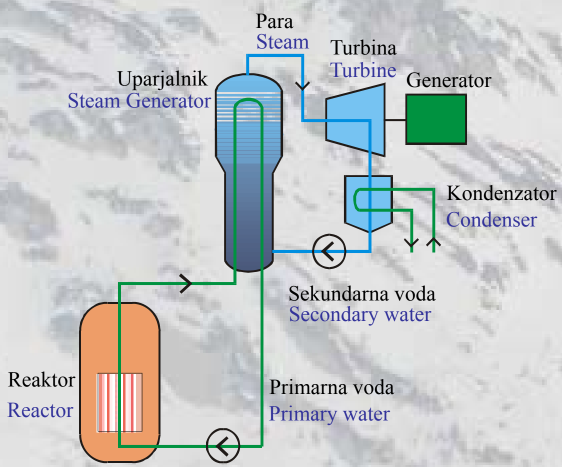
Moderated and cooled by ordinary water. Water **boils in the reactor**, steam drives the turbine.



Vrelna elektrarna je podobna termoelektrarni, le da ima namesto kotla reaktor.

A BWR is similar to a thermal power plant, having a reactor instead of a boiler.

Tlačnovodna jedrska elektrarna
PWR (Pressurized Water Reactor)



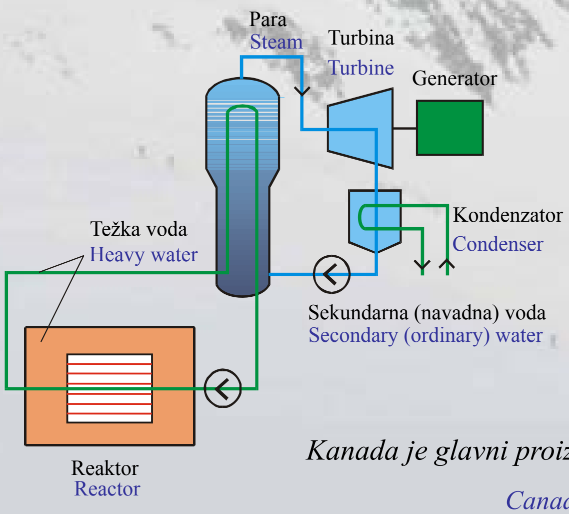
Moderirana in hlajena je z navadno vodo. Primarna **voda je pod tlakom in zato ne vre**. Uparja se sekundarna voda.

Moderated and cooled by ordinary water. Primary water is **pressurized and doesn't boil**. Secondary water boils in steam generators.

Tlačnovodnih elektrarn je največ. Mednje sodi tudi NE Krško.

PWRs are the most common plants. Krško NPP is a PWR.

Težkovodna jedrska elektrarna
PHWR (Pressurized Heavy Water Reactor)



Moderirana in hlajena je **s težko vodo**. Voda v reaktorju ne vre. Uparja se sekundarna voda v uparjalniku. Za gorivo lahko uporablja naravni uran.

Moderated and cooled **by heavy water**. Primary water in the reactor doesn't boil. Secondary water boils in steam generators. Natural uranium can be used as the fuel.

Kanada je glavni proizvajalec težkovodnih elektrarn, ki so poznane pod imenom CANDU.

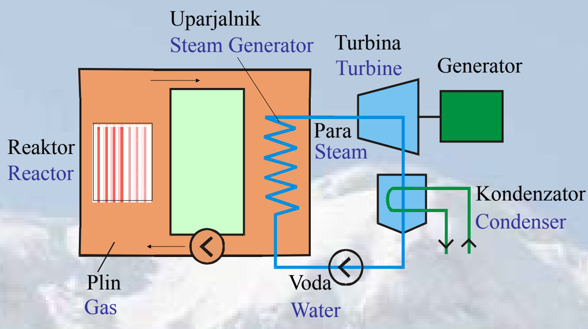
Canada is the major producer of PHWRs, known as CANDU.

Jedrska elektrarna, hlajena s plinom
GCR, AGR (Gas Cooled Reactor, Advanced Gas cooled Reactor)

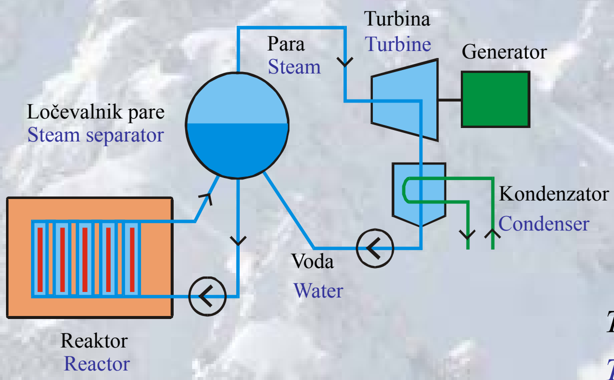
Moderirana je z **grafitom** in hlajena s **plinom** (CO_2).
Plin greje vodo, ki se uparja in poganja turbino.
Tip GCR deluje na naravni uran.

Moderated with **graphite** and cooled by **gas**.
The gas (CO_2) heats water which vaporizes and drives the turbine.
The GCR type uses natural uranium.

Plinske elektrarne obratujejo v Veliki Britaniji.
Gas cooled reactors operate in Great Britain.



Vodno hlajena, grafitno moderirana jedrska elektrarna
LWGR (Light Water cooled Graphite moderated Reactor)



Moderirana je z **grafitom** in hlajena z **navadno vodo**. Voda vre v reaktorju, para se loči od kapljevine v ločevalniku pare.

Moderated with **graphite** and cooled by **ordinary water**. Water boils in the reactor, steam is separated from liquid in the steam separator.

Take vrste je bila elektrarna v Černobilu.
The Chernobyl plant was of that type.

Ostale vrste reaktorjev
Other Types of Reactors

Poleg reaktorjev v jedrskih elektrarnah je po svetu tudi okoli **250 raziskovalnih, poskusnih, šolskih in proizvodnih** reaktorjev.

In addition to reactors in nuclear power plants, there are about **250 research, testing, training and production** reactors in the world.

Plovila na jedrski pogon
Nuclear-Powered Vessels

Na plovilih raznih držav (**podmornice, letalonosilke in ledolomilci**) je vgrajenih več kot **500** pogonskih jedrskih reaktorjev.

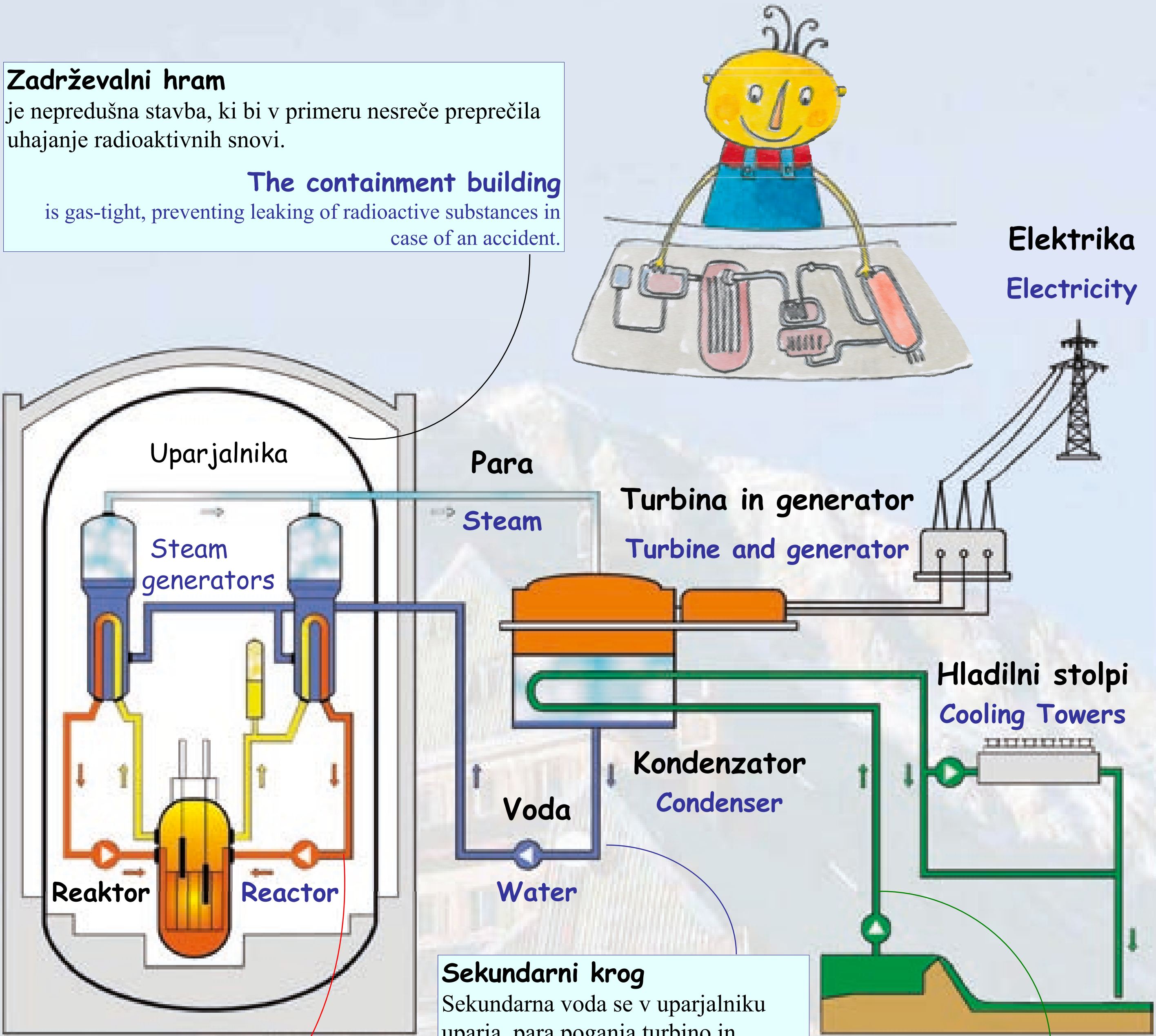
There are more than **500** reactors on nuclear-powered vessels (**submarines, aircraft carriers, icebreakers**) around the world.

Shema Jedrske elektrarne Krško

Plan of the Krško Nuclear Power Plant

Zadrževalni hram
je nepredušna stavba, ki bi v primeru nesreče preprečila uhajanje radioaktivnih snovi.

The containment building
is gas-tight, preventing leaking of radioactive substances in case of an accident.



Sekundarni krog
Sekundarna voda se v uparjalniku uparja, para poganja turbino in generator. Izrabljena para kondenzira v kondenzatorju in se kot voda vrača v uparjalnik.

Secondary System
Secondary water is vaporized in the steam generator, the steam drives the turbine and the generator. Turbine exhaust steam is condensed into water in the condenser and pumped back into steam generator.

Terciarni (tretji) krog
Savska voda hladi kondenzator in se vrača v Savo.

Tertiary Cycle
Water from the river Sava is used to cool the condenser and flows back into the river.

Primarni krog
V reaktorju se sprošča toplota, ki jo primarna voda v uparjalniku prenaša na sekundarno vodo.

Primary System
Heat released in the reactor core is transported by the primary water to steam generators.

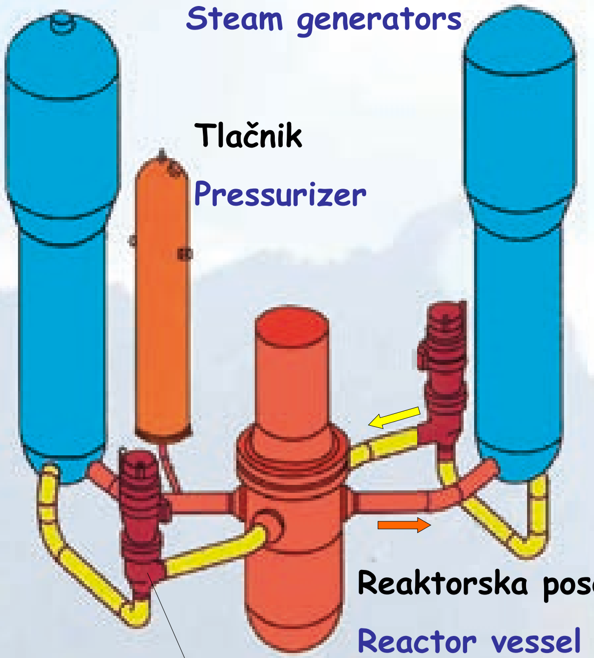
Hladilni stolpi

Če ni dovolj vode v reki Savi, se vključijo hladilni stolpi.

Cooling Towers
If there is not enough water in the river Sava, cooling towers are put to service.

Primarni krog

Primary System



Tlačnik je posoda, s katero vzdržujemo potrebni tlak v primarnem krogu.

The **pressurizer** is a vessel used to control the pressure in the primary cycle.

V **uparjalnikih** se toplota prenaša skozi stene številnih cevi na sekundarno stran.

In the **steam generators**, heat is transferred through the walls of numerous tubes into the secondary system.

Prerez uparjalnika

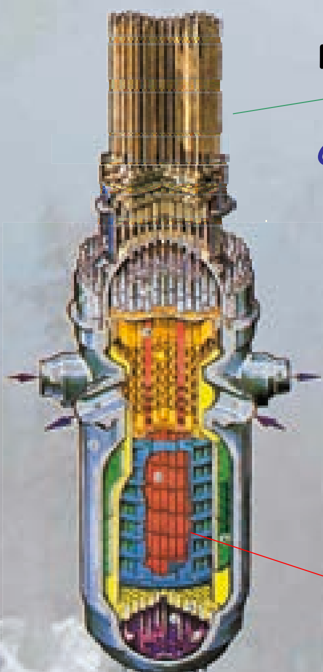
Steam Generator

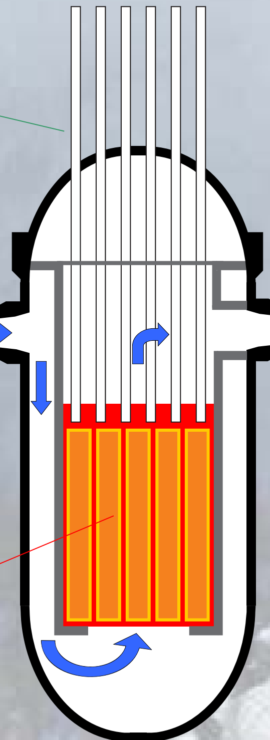
Primarni črpalki vzdržujeta stalen pretok primarne vode.

Two **primary pumps** maintain a constant flow of water in the primary system.

V **reaktorski posodi** je zloženo jedrsko gorivo. Sproščena toplota segreva primarno vodo.

The **reactor vessel** holds the nuclear fuel. The heat generated in it heats water in the primary system.





Pogled v prvo sredico reaktorja, v kateri je zloženo sveže gorivo.

A view of the first reactor core loaded with fresh fuel.

Komandna soba

The Control Room

V komandno sobo se kot po živčevju stekajo vsi podatki o delovanju elektrarne.

The control room is the 'brain' of the plant, from where information on all the plant's operations is monitored.

Operaterji nadzirajo obratovanje sistemov in jih upravljajo s pomočjo stikal in gumbov na komandnih ploščah.

Operation of the plant is controlled by operators using control switches on control panels.

Simulator

Simulator

Simulator je kopija komandne sobe, simulirani odzivi so enaki odzivom elektrarne.

The simulator is a copy of the control room, where the simulated responses are equal to the responses of the power plant.

Usposabljanje operaterjev

Simulator je zelo pomemben pri usposabljanju operaterjev.
Vsak operater je 4 tedne na leto na usposabljanju, od tega 80 ur na simulatorju.

Operators training

The simulator is very important for the training of operators.
Each operator has 4 weeks training each year, of which 80 hours is on a simulator.

Remont v jedrski elektrarni Krško

Outage at the Krško NPP

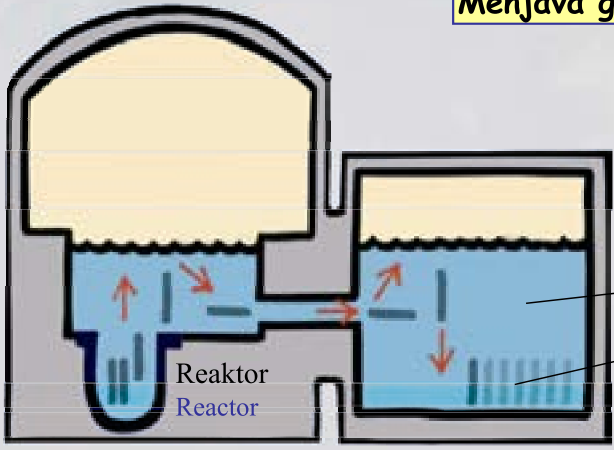
Redna vzdrževalna dela v elektrarni trajajo približno en mesec.

Regular maintenance work at the Krško power plant lasts approximately one month.

Od leta 2004 dalje se remont izvaja na 18 mesecev.

Since 2004 the outage takes place every 18 months.

Menjava goriva — Refuelling



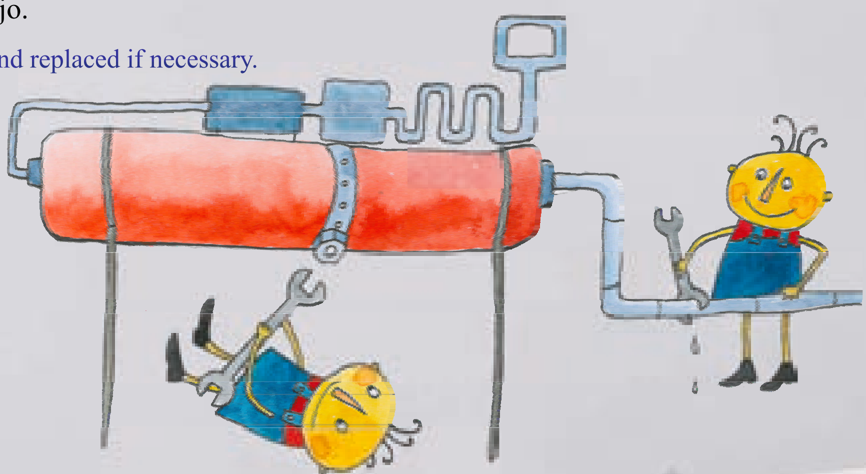
Izrabljeno gorivo iz reaktorja pod vodo premestijo v bazen za izrabljeno gorivo. V reaktor vstavijo sveže gorivo.

Spent fuel from the reactor is transferred under water to the spent fuel pool and fresh fuel is inserted into the reactor.

Vzdrževanje opreme — Equipment Maintenance

Opremo preverijo in po potrebi zamenjajo.

During an outage, equipment is checked and replaced if necessary.



Testiranje opreme — Equipment Testing

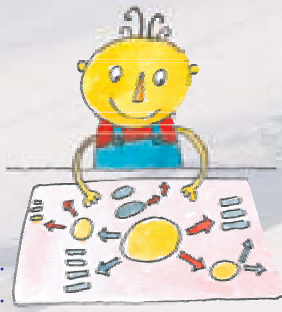
Opremo, ki normalno ne obratuje in je v pripravljenosti, testirajo med remontom.

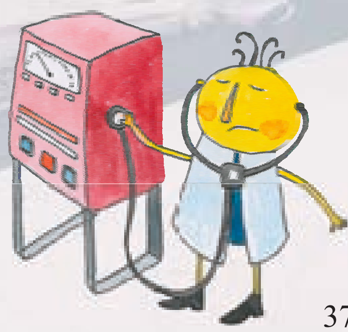
Equipment that is not used during normal operation of the plant is tested during outages.

Načrtovanje del — Planning of Activities

Bistveno je skrbno načrtovanje vseh del. Vsaka ura zamude stane …

Careful planning of all activities is essential. Each hour of delay is costly ...





Posodabljanje jedrske elektrarne Krško je stalen proces

Modernization of the Krško NPP is an Ongoing Process

Večji projekti

Major projects

Leto 2000: zamenjava uparjalnikov

Year 2000: replacement of the steam generators

Leto 2006: zamenjava nizkotlačnih turbin

Year 2006: low pressure turbine replacement

Leto 2010: zamenjava električnega generatorja

Year 2010: electric generator replacement

Leto 2012: zamenjava pokrova reaktorja

Year 2012: reactor vessel head replacement

Posodabljanje je omogočilo povečanje moči elektrarne s prvotnih 632 MW na sedanjih 696 MW ter znatno izboljšanje jedrske varnosti.

Modernization allowed uprating from the initial 632 MW to 696 MW and significant improvement of nuclear safety.

Reaktorji III. generacije

Generation III reactors

Značilnosti tretje generacije jedrskih reaktorjev:

- standardizirana zasnova,
- dolga projektna življenjska doba (tipično 60 let),
- zmanjšana možnost nesreče s taljenjem sredice,
- majhna količina radioaktivnih odpadkov.

Properties of third generation Nuclear Reactors:

- Standardized design,
- Long design lifetime (typically 60 years),
- Low possibility of core melt accident,
- Small amount of radioactive waste.

Areva EPR

(European Pressurized Water Reactor)

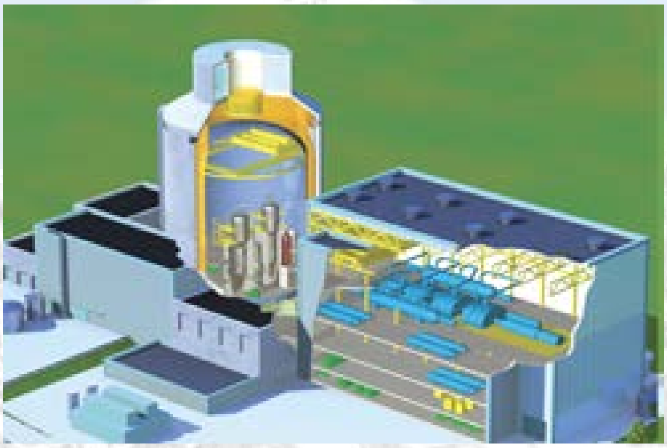
francosko / nemška tehnologija
v gradnji na Finskem, v Franciji in na Kitajskem

French / German technology
under construction in Finland, France and China

Westinghouse AP1000

inovativna ameriška tehnologija
v gradnji v ZDA in na Kitajskem

innovative American technology
under construction in USA and China



Reaktorje III. generacije proizvajajo tudi na Japonskem, v Rusiji in Južni Koreji.

Generation III. reactors are produced also in Japan, Russia and South Korea.

Slovenija bo morala v prihodnosti sprejeti odločitev o gradnji drugega bloka jedrske elektrarne Krško.

Slovenia is considering construction of the second unit of NPP Krško.

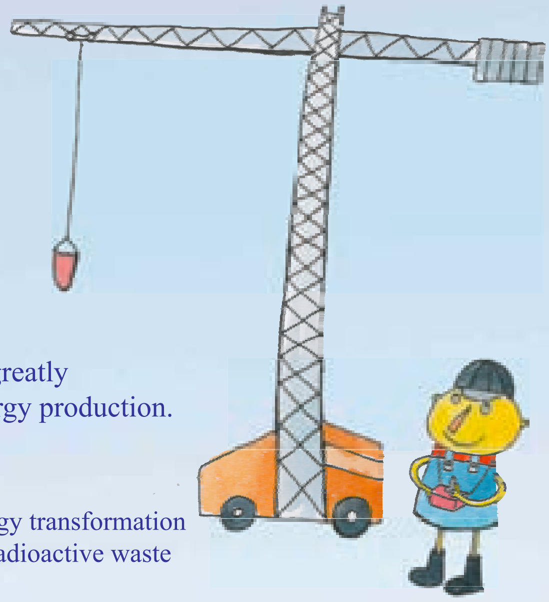
Reaktorji IV. generacije

Generation IV Reactors

Reaktorji IV. generacije bodo pomembno prispevali k vzdržnemu pridobivanju energije.

Glavne prednosti:
- varnost
- velik izkoristek izrabe goriva in pretvorbe energije
- možnost jedrskega sežiganja radioaktivnih odpadkov
- majhna možnost uporabe jedrskih snovi v vojaške namene

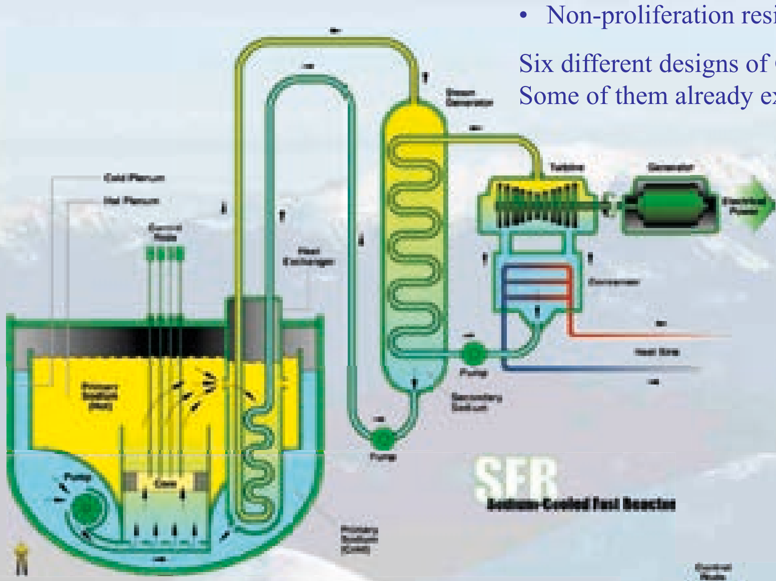
Razvijajo 6 različnih zasnov reaktorjev IV. generacije. Nekatere med njimi že obstajajo kot eksperimentalni reaktorji.



Generation IV reactors will greatly contribute to sustainable energy production.

Main advantages:
- Safety
- Efficient use of fuel and energy transformation
- Possible nuclear burning of radioactive waste
- Non-proliferation resistance

Six different designs of Gen IV reactors are being developed. Some of them already exist as experimental reactors.



Hitri natrijev reaktor

Sodium-Cooled Fast Reactor

S takimi reaktorji imamo največ izkušenj doslej. Lahko proizvede več goriva kot ga porabi (**oplodni reaktor**).

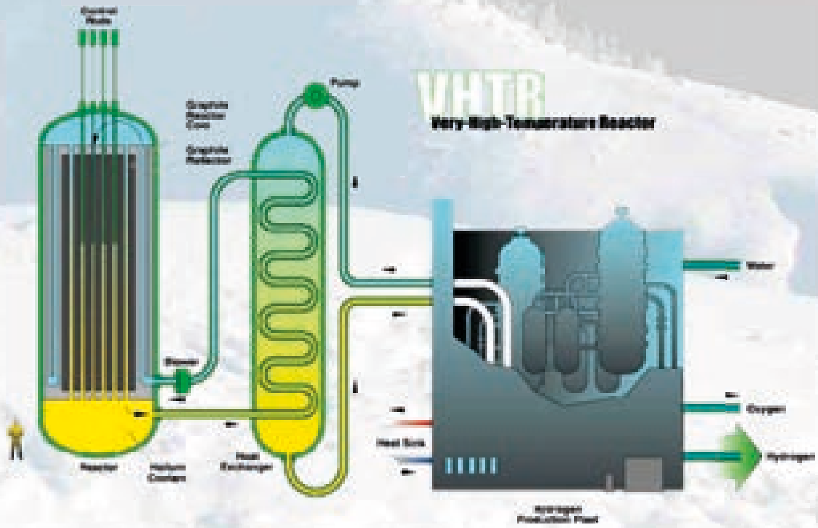
Most experience has been gained with this technology so far. It can produce more new fuel than has been used (**breeder reactor**).

Zelo visoko temperaturni reaktor

Very-High-Temperature Reactor

Visoka temperatura hladila (helija) je idealna za proizvodnjo **vodika**.

The very high temperature of the helium coolant is ideal for production of **hydrogen**.



Druge vrste reaktorjev IV. generacije so še:

- Hitri plinski reaktor
- Hitri svinčev reaktor
- Reaktor na staljeno sol
- Reaktor z nadkritično vodo

Other Generation IV reactor designs include:

- Gas-Cooled Fast Reactor
- Lead-Cooled Fast Reactor
- Molten Salt Reactor
- Supercritical-Water-Cooled Reactor

Jedrsko gorivo

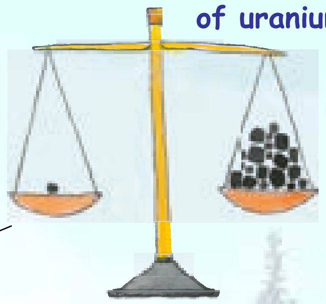
Nuclear Fuel

Naravni uran vsebuje 99,3 % ^{238}U in le 0,7 % ^{235}U. Večina reaktorjev obratuje na **obogaten** uran (~ 4 % ^{235}U).

Natural uranium consists of 99.3% ^{238}U and 0.7% ^{235}U. Most reactors need **enriched** uranium (~ 4% ^{235}U).

Jedrsko gorivo je v obliki **tabletk uranovega dioksida**.

Nuclear fuel is in the form of **pellets of uranium dioxide**.



Le reaktorji, ki imajo za moderator **grafit** ali **težko vodo**, lahko za gorivo uporabljajo **naravni uran**.

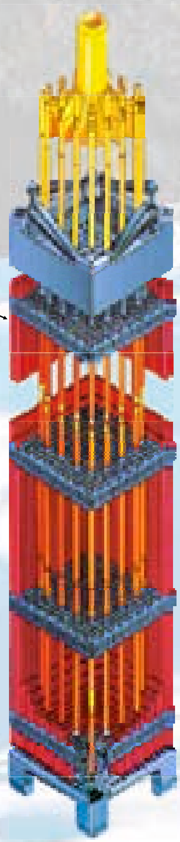
Only **graphite-** or **heavy water-**moderated reactors can use **natural uranium** as nuclear fuel.

Iz ene tabletke goriva (7 g) pridobimo enako količino energije kot iz 1 tone premoga.

One fuel pellet (7 g) can produce the same amount of energy as 1 ton of coal.

Tabletke so nepredušno zaprte v kovinsko cev – **gorivno palico**.

Fuel pellets are sealed inside a metal tube – the **fuel rod**.



Gorivni element je snop gorivnih palic. Reaktor jedrske elektrarne Krško vsebuje 121 gorivnih elementov, vsak izmed njih vsebuje 235 gorivnih palic.

A **fuel element** is a bundle of fuel rods. There are 121 fuel elements in the reactor of Krško NPP, each containing 235 fuel rods.

Gorivni element je v reaktorju tipično 3-4 leta.

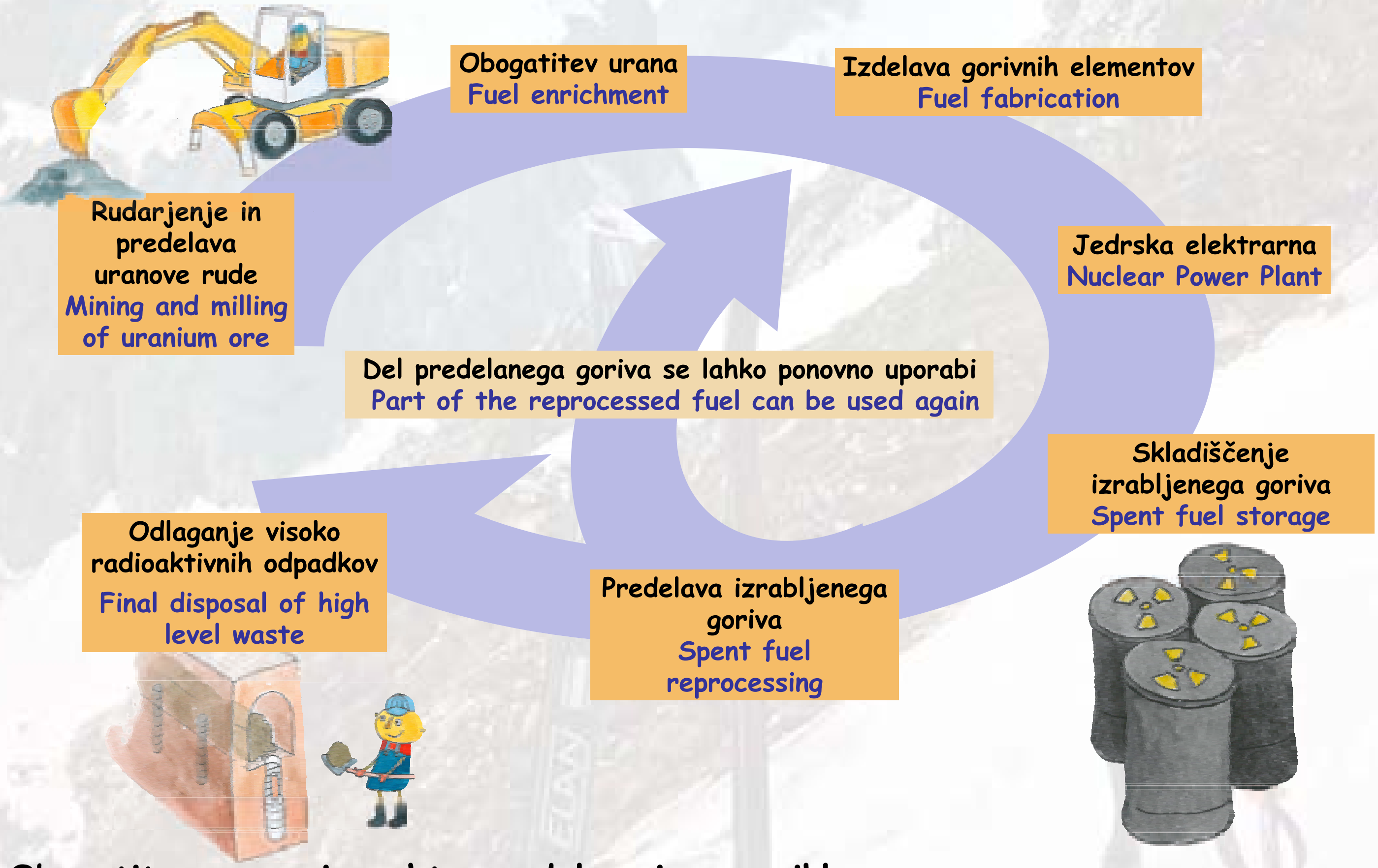
Typically a fuel element spends 3-4 years in the reactor.

Jedrski gorivni ciklus

Nuclear Fuel Cycle

Jedrski gorivni ciklus imenujemo pot jedrskega goriva od rudarjenja do končnega odlaganja.

The Nuclear Fuel Cycle is the sequence of events from mining of uranium ore to final disposal of spent fuel.



Obogatitev urana je zahteven del gorivnega cikla.

Uranium enrichment is a demanding part of the fuel cycle.

Uran obogatijo v plinskih centrifugah

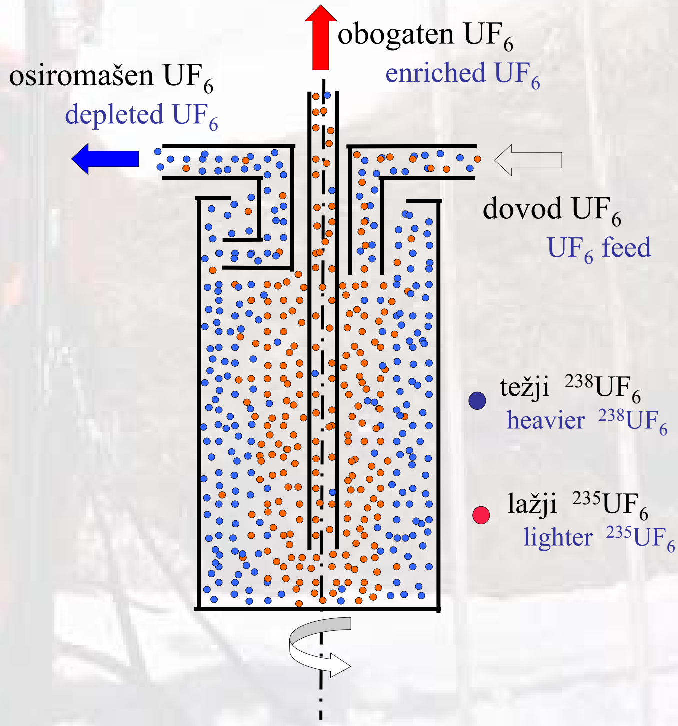
Uran iz rude kemično spremenijo v uranov heksafluorid (UF_6 – plin). V centrifugah se lažje molekule $^{235}UF_6$ ločijo od težjih $^{238}UF_6$.

Fuel is enriched in gas centrifuges

Uranium from the ore is chemically converted into uranium hexafluoride (UF_6 – gas). In centrifuges lighter $^{235}UF_6$ molecules separate from the heavier $^{238}UF_6$.

Shema plinske centrifuge

Gas centrifuge scheme



Jedrski gorivni ciklus
Zaključni del

Nuclear Fuel Cycle
Back End

Skladiščenje izrabljenega goriva

Spent fuel storage

Izrabljeno gorivo ostane več let v bazenu znotraj elektrarne. Po nekaj letih je možno suho skladiščenje v zračno hlajenih zabojnikih.

Spent fuel is stored in a pool within the plant for several years. After some years dry storage of fuel in air cooled casks is also possible.

Bazen za izrabljeno gorivo

Spent fuel pool

Zabojnik za izrabljeno gorivo

Spent fuel cask

Predelava goriva zelo zmanjša količino odpadkov

Reprocessing greatly reduces the amount of waste

V tovarni za predelavo izločijo iz izrabljenega goriva dolgožive radioaktivne izotope.
S tem se zelo zmanjša prostornina odpadkov, hkrati se ohrani uporaben del goriva.

In the reprocessing facility, long lived radioactive isotopes are removed from spent fuel.
The volume of waste is greatly reduced, while saving the reusable part of fuel.

Tovarna za predelavo goriva

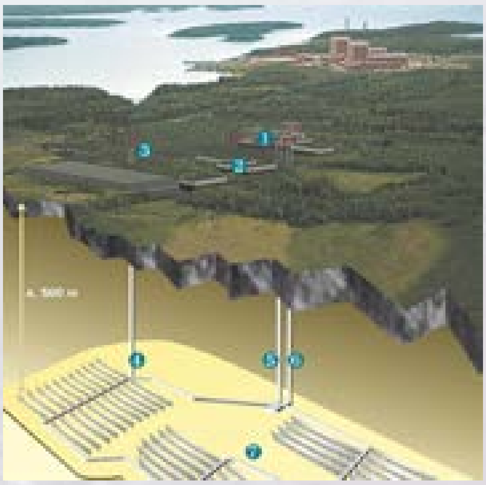
Reprocessing facility

Odlaganje odpadkov

Final disposal of waste

Najugodnejša rešitev je odlaganje v globoke geološke plasti. Odpadki so lahko v obliki stekla ali kot celi gorivni elementi zaprti v korozijsko odpornih zabojnikih. Prvo odlagališče bo zgrajeno okoli leta 2020.

Disposal in deep geological repositories is the preferred option. The waste forms envisaged for disposal are vitrified high-level waste or spent fuel bundles in corrosion-resistant canisters. The first permanent disposal is expected to operate about 2020.



Zamisel odlagališča izrabljenega goriva v Olkiluotu na Finskem

The concept of spent fuel disposal in Olkiluoto, Finland

Fuzija ali zlivanje jeder

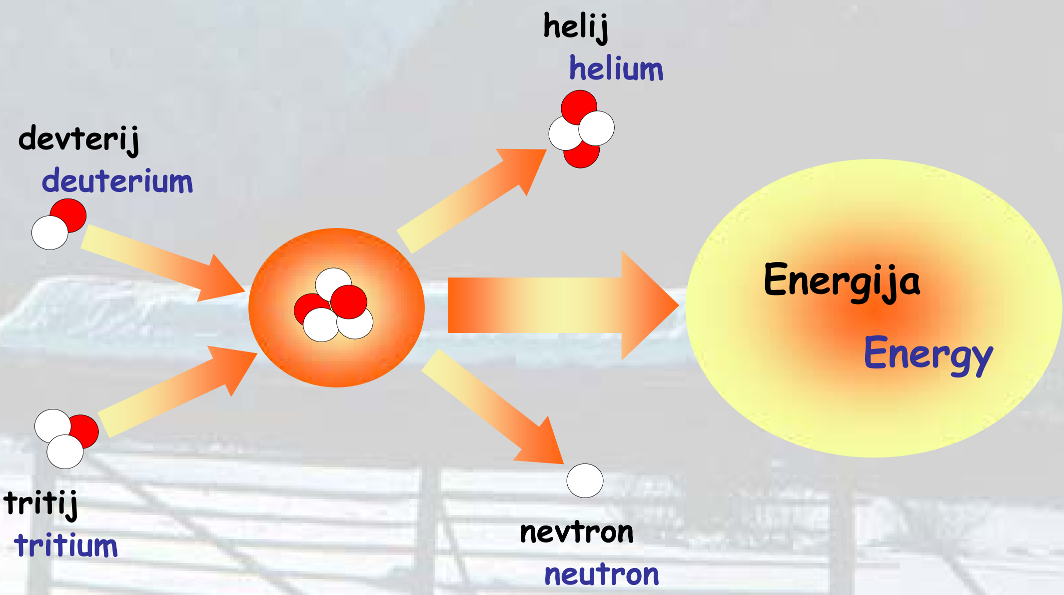
Nuclear Fusion

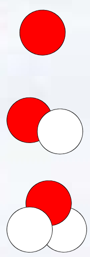
Fuzija je vir **energije Sonca**. Jedra vodika se ob visoki temperaturi in visokem tlaku, ki je posledica težnosti, zlivajo v helij.

Fusion reactions **power the Sun**. At high temperatures and under extreme pressure of gravity hydrogen is converted into helium.

Eksperimentalni fuzijski reaktorji in prve fuzijske elektrarne bodo delovali na zlivanje devterija in tritija pri temperaturi okoli sto milijonov stopinj.

Experimental fusion reactors and the first fusion power plants will be powered by fusion of deuterium and tritium at temperature around a hundred million degrees.





Jedro vodika je proton.

The nucleus of hydrogen is a proton.

Jedro devterija sestavljata proton in nevtron.

The nucleus of deuterium consists of a proton and a neutron.

Jedro tritija sestavljata proton in dva nevtrona.

The nucleus of tritium consists of a proton and two neutrons.

Tritij bo nastajal z jedrsko reakcijo iz litija v plašču fuzijskega reaktorja.

Tritium will be produced by nuclear reaction with lithium in the blanket of the fusion reactor.

ITER – eksperimentalni fuzijski reaktor

ITER – Experimental Fusion Reactor

Gradijo ga v Cadarachu, Francija

Under construction in Cadarache, France

Fuzijska moč	500 MW	Total fusion power
Faktor ojačitve*	10	Amplification factor*
Prostornina plazme	850 m^3	Plasma volume

* Količnik med proizvedeno močjo in močjo za segrevanje plazme

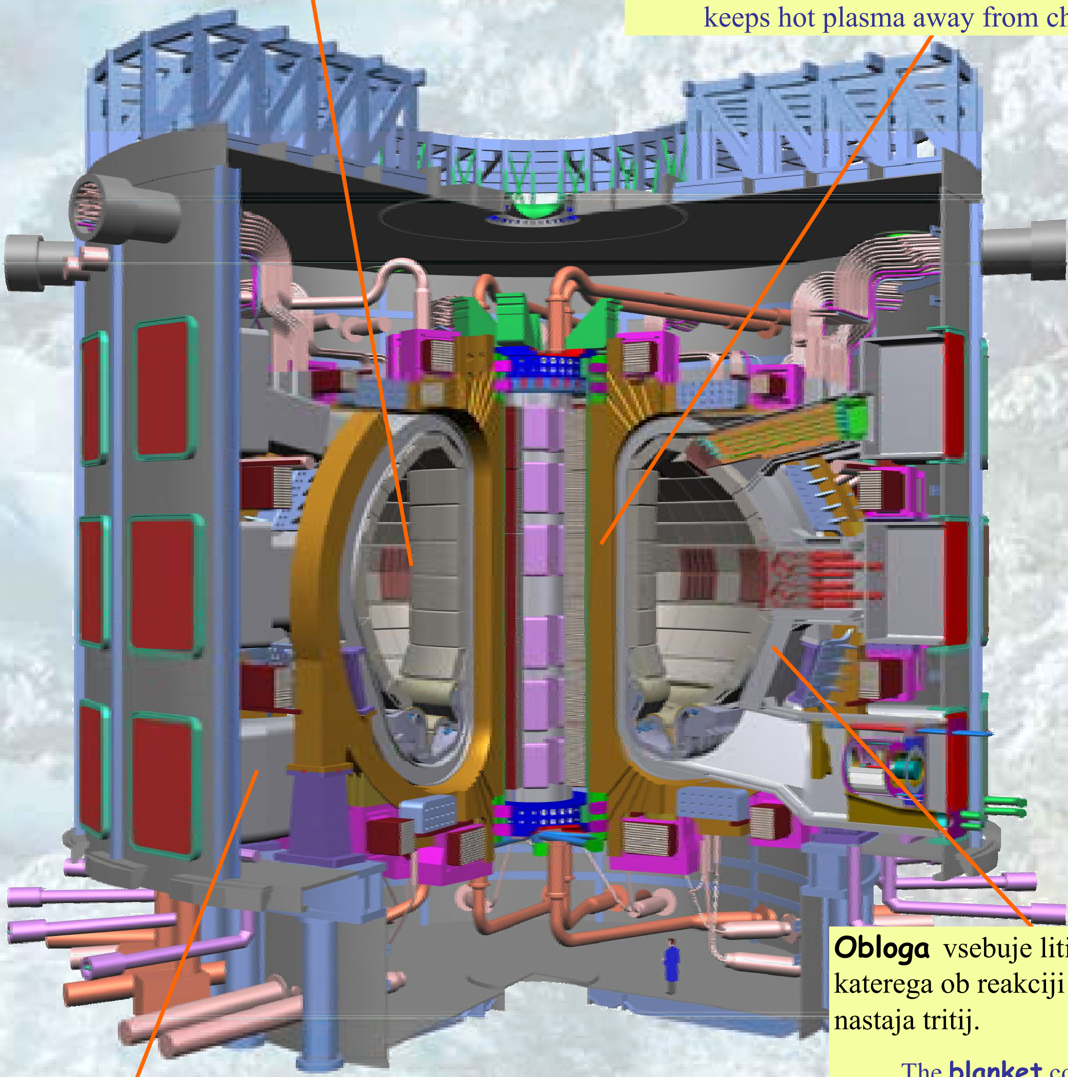
* Ratio between the power generated and the power injected into the plasma

Devterij in tritij se v stanju plazme zlivata v fuzijski komori.

Deuterium and tritium fuse in the plasma state inside the fusion chamber.

Magnetno polje **superprevodnih tuljav** drži vročo plazmo stran od sten komore.

Magnetic field of **superconducting coils** keeps hot plasma away from chamber wall.



Obloga vsebuje litij, iz katerega ob reakciji z nevtroni nastaja tritij.

The **blanket** contains lithium for breeding of tritium by means of reaction with neutrons.

Temperatura znotraj ohišja mora biti -200 °C, da tuljave postanejo superprevodne.

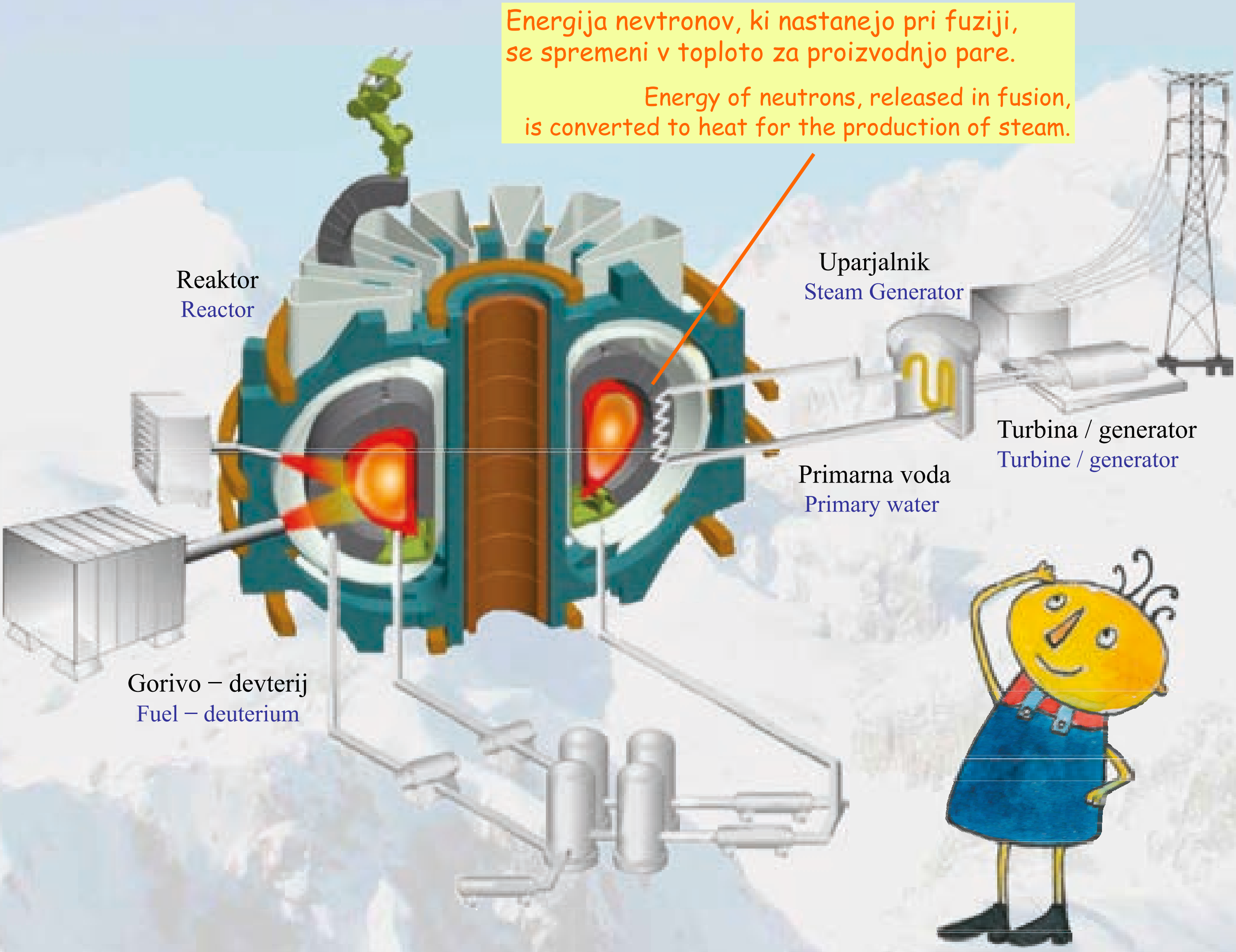
Temperature inside the housing is -200 °C for superconductivity of the coils.

Reaktorji V. generacije

Generation V Reactors

Reaktorji V. generacije bodo fuzijski reaktorji, v katerih se bodo jedra devterija in tritija ob visoki temperaturi zlivala v helij. Pri tem se bo sproščalo ogromno energije.

Generation V reactors will produce great amounts of energy by fusion of deuterium and tritium into helium.



Fuzijske elektrarne bodo temeljile na izkušnjah eksperimentalnih fuzijskih reaktorjev. Pričakujemo, da bodo začele obratovati čez 40 let.

Fusion power plants will be based on the experience from experimental fusion reactors. Operation is expected in 40 years.

Fuzijska elektrarna z električno močjo 1000 MW bo porabila letno 100 kg devterija in 3 tone litija.

Fuel consumption of a 1000 MW fusion power plant will be 100 kg of deuterium and 3 tons of lithium per year.

Sevanje okolja

Background Radiation

Doza sevanja je merilo obsevanosti.
Biološki učinki so ji približno sorazmerni.

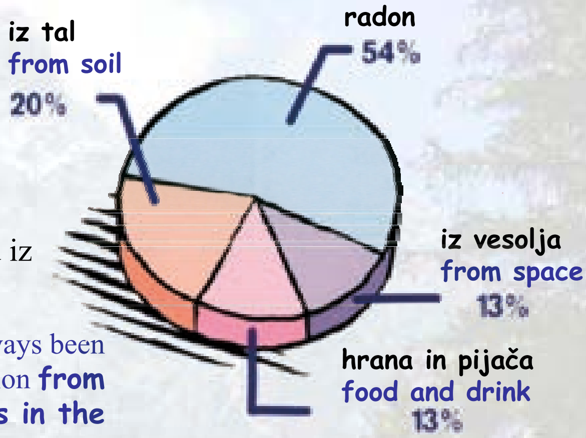
Radiation **dose** is a measure of irradiation.
Biological effects are approximately proportional to dose.

Enota za dozo je **sivert (Sv).**
The unit of dose is the **sievert (Sv).**

1 Sv = 1000 mSv (milisivert)

Že od nekdaj smo izpostavljeni sevanju iz **virov v okolju.**

Humans have always been exposed to radiation **from sources in the environment.**



Letna doza iz **naravnega okolja v Sloveniji je 2,5 do 2,8 mSv**, kar je zaradi višjega prispevka radona nekoliko višje od svetovnega povprečja (2,4 mSv).

The annual dose from **natural sources in Slovenia is 2.5 to 2.8 mSv**, slightly higher than the world average (2.4 mSv) due to a higher contribution from radon.

Letna doza iz **umetnih virov** (medicina, industrija) je **0,4 do 1,5 mSv.**

The annual dose from **artificial sources** (medicine, industry) is **0.4 to 1.5 mSv.**

Letni prispevek iz **NE Krško** je okoli **0,001 mSv**.

The annual dose from **Krško NPP** is about **0.001 mSv**.

V Sloveniji je celotna doza zaradi **černobilske nesreče** približno **0,72 mSv**.
Celotna doza dosedanjih jedrskih poskusov (1950-1970) je **7,2 mSv**.

In Slovenia, the total dose from the **Chernobyl accident** is **0.72 mSv**.
The total contribution from nuclear tests (1950-1970) is **7.2 mSv**.

Polet iz Evrope v ZDA prispeva okoli **0,05 mSv**.

A **flight** from Europe to the USA results in a dose of about **0.05 mSv**.

Radon v bivalnem okolju

Radon in Homes

Žlahtni plin **radon** nastaja z radioaktivnim razpadom urana in torija v zemlji. Izhaja iz tal in se kopiči v slabo prezračenih prostorih.

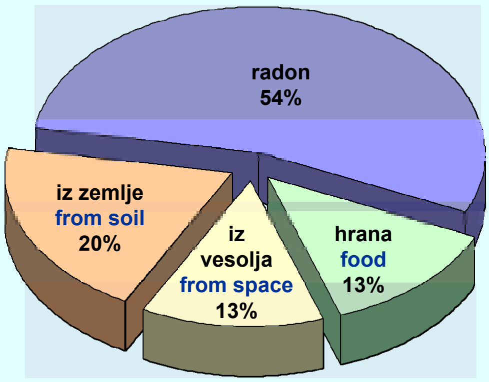
The inert gas **radon** is a daughter product of the radioactive decay of uranium and thorium in the soil. It seeps through floors and accumulates in insufficiently ventilated rooms.

Potomci radona ostanejo v zraku kot lebdeči radioaktivni delci, ki ob vdihavanju povečajo tveganje za nastanek raka na dihalih.

Radon decay products remain suspended in the air. When inhaled they increase the risk of lung cancer.

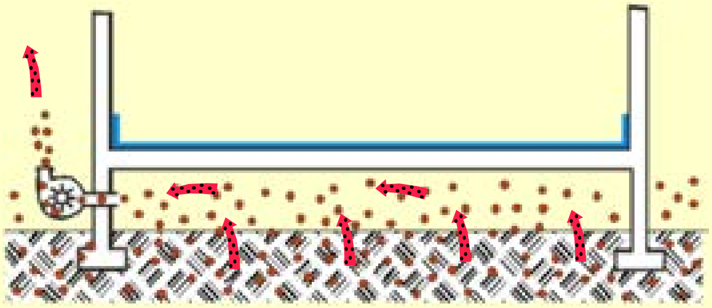
Sevanje radona in njegovih potomcev že od nekdaj predstavlja največji delež (preko polovice) naravnega sevanja okolja.

Radiation from radon and its decay products represents the biggest share (approximately 50%) of natural background radiation.



Koncentracija radona v bivalnih prostorih v Sloveniji je okoli 60 Bq/m^3.

The radon concentration indoors in Slovenia is around 60 Bq/m^3.



Če bi koncentracija radona povzročila letno dozo, večjo od 6 mSv, Uprava RS za varstvo pred sevanji priporoča sanacijo (možno je npr. odsesavanje zraka izpod talne plošče).

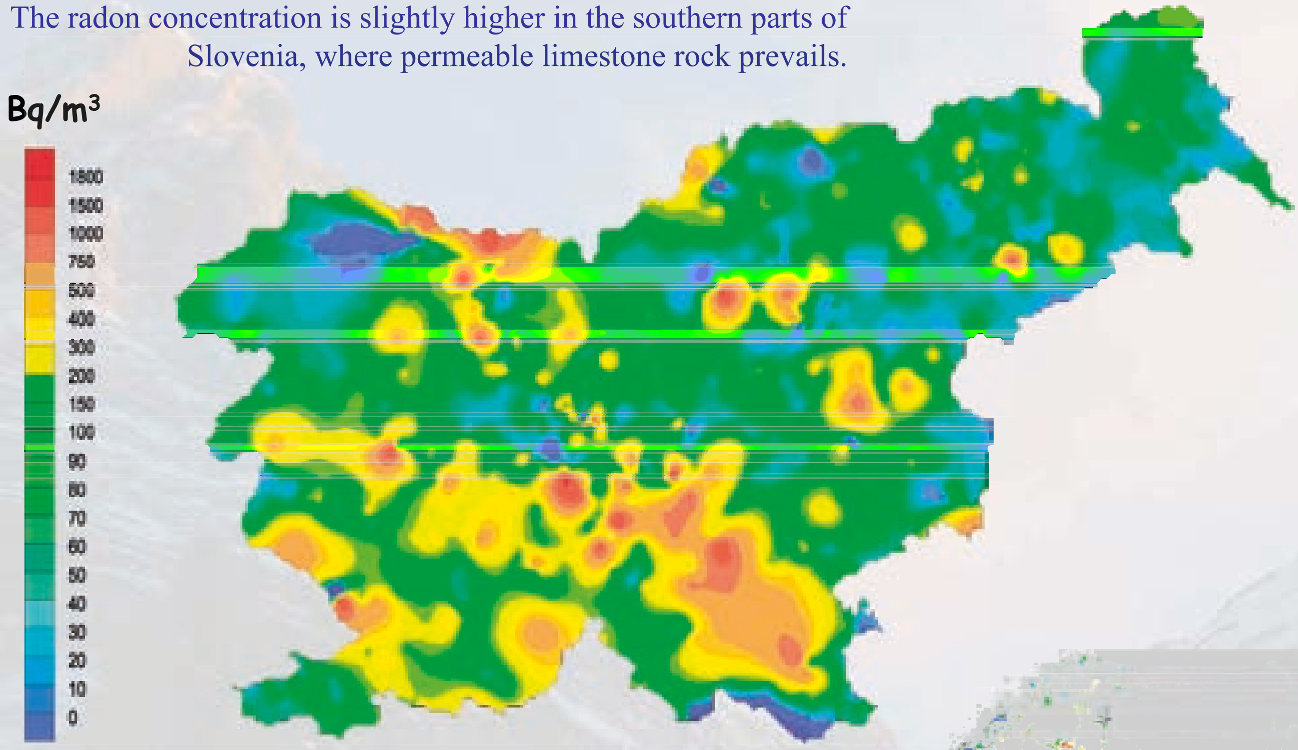
Should the radon concentration cause an annual dose higher than 6 mSv, the Radiation Protection Administration recommends remedial measures (e.g. pumping of air from under the floor).

Koncentracija radona v bivalnih prostorih

Radon Concentration in Homes

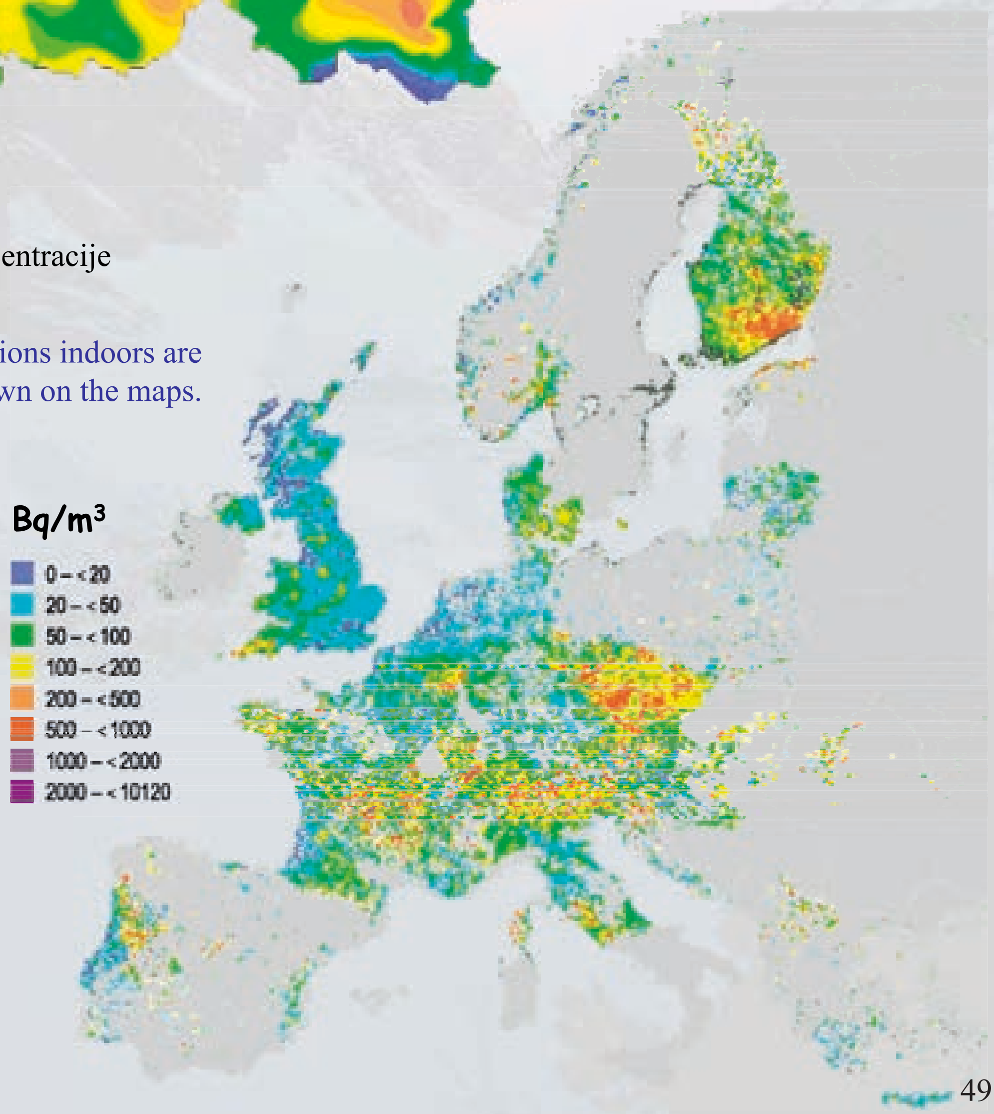
V Sloveniji je koncentracija radona nekoliko višja v njenem južnem delu, kjer prevladuje bolj prepusten kraški svet.

The radon concentration is slightly higher in the southern parts of Slovenia, where permeable limestone rock prevails.



Zemljevida kažeta srednje koncentracije radona v zaprtih prostorih.

Average radon concentrations indoors are shown on the maps.



Trenutne koncentracije radona se lahko spreminjajo glede na letni čas, vreme in dnevno zračenje prostorov.

The actual concentrations of radon and its decay products change and depend on the season, the weather and ventilation of rooms.

Učinki radioaktivnega sevanja na živa bitja

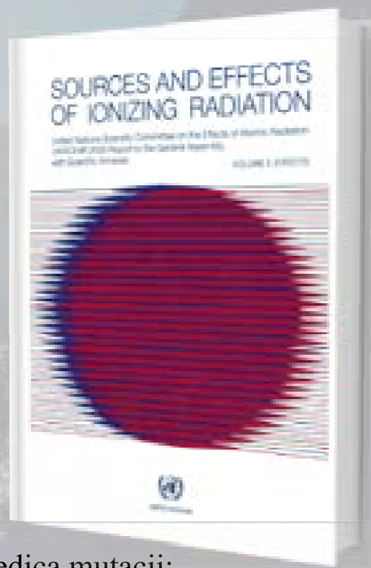
Effects of Radiation on Living Beings

Radioaktivno sevanje lahko poškoduje žive celice. Večina poškodovanih celic odmre, nekatere pa doživijo spremembo ali **mutacijo**. Tudi v naravi se celice stalno delijo, obnavljajo in odmirajo. Sevanje pospeši naravno odmiranje celic in poveča število mutacij.

Ionizing radiation can damage living cells. Most of the damaged cells die, some may mutate. In the natural environment cells also constantly divide, reproduce and die. Radiation accelerates the death of cells and increases the number of mutations.

Učinke sevanja poznamo na osnovi 50 let trajajoče študije Združenih narodov 86572 preživelih po bombardiranju Hirošime in Nagasakija, med katerimi jih je 421 umrlo zaradi raka, ki je bil posledica radioaktivnega sevanja.

Detailed knowledge of the effects of radiation was obtained from a United Nations' 50-year study of consequences in survivors of the Hiroshima and Nagasaki atomic bombs. Among 86527 survivors 421 died of cancers caused by ionizing radiation.



Pri nizkih dozah se <u>lahko</u> pojavijo **zakasneli učinki** (po nekaj letih) ki so posledica mutacij:

- rak
- dedne posledice

Verjetnost zanje je sorazmerna dozi sevanja.

Low doses of ionizing radiation may have **delayed effects** (after several years) due to mutations:

- cancer
- hereditary effects

The likelihood of delayed effects is proportional to radiation dose.

Pri visokih dozah (nad 500 mSv) se pojavijo **takojšnji učinki** (v nekaj dneh), ki so posledica odmiranja celic:

- sprememba krvne slike
- opekline
- smrt (nad ~ 3500 – 5000 mSv)

High doses (above 500 mSv) over short periods of time cause **immediate effects** due to the death of many cells:

- blood count changes
- radiation burns
- death (above ~ 3500 – 5000 mSv)

Biološke učinke sevanja koristno uporabimo pri zdravljenju raka. Rakave celice, ki so manj odporne kot zdrave, obsevanje uniči, zdrave ga preživijo.

The biological effects of radiation are beneficially used in cancer therapy, because cancer cells are much less resistant to radiation than healthy cells.

Linearni pospeševalnik za obsevanje v medicini

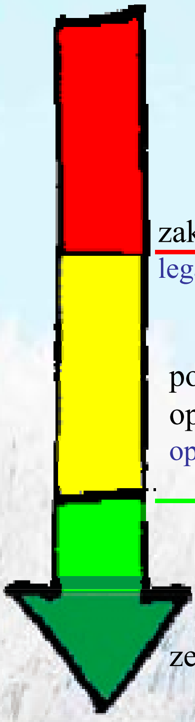
Linear accelerator for medical irradiation

Varstvo pred sevanji

Radiation Protection

Temeljno izhodišče: koristi od uporabe radioaktivnih snovi in sevanja morajo biti večje od škode zaradi obsevanja!

Basic principle: benefits from the use of radioactive substances and radiation must be greater than the harmful effects of iradiation!



Omejevanje izpostavljenosti sevanju

Limitation of Radiation Exposure

zakonska omejitev — Doza ne sme nikoli biti večja.

legal limit — Dose may never be higher.

področje optimizacije — Trudimo se čim bolj znižati dozo.

optimization — We try to reduce dose.

Ne splača se vlagati v nižanje doze.

It is not worth reducing dose further.

zelo nizka doza

very low dose

Znak radioaktivnosti v jedrski elektrarni

Radioactivity symbol in a nuclear power plant

S sevanjem smejo delati samo strokovnjaki v primerni zaščitni opremi in ob rednem zdravniškem nadzoru.

Only professionals with suitable protective equipment and under regular medical surveillance are allowed to work with radiation.

Monitor radioaktivnosti

Radioactivity monitor

Raziskovalni reaktor TRIGA pri Ljubljani

TRIGA Research Reactor Near Ljubljana

Deluje od leta 1966.
Na svetu je več kot 40 reaktorjev tega tipa.

Izdelovalec: General Atomics, ZDA

Tehnični podatki

Največja moč: 250 kW

Gorivo: obogaten uran (do 20 % U-235)

Potrebna masa urana: 2,3 kg U-235

Moderator: cirkonijev hidrid

Hladilo: navadna voda, naravna konvekcija

Regulacijske palice (4): borov karbid

Varnost

Reaktor se ugasne sam (brez posredovanja človeka ali tehničnih sistemov), če se preveč segreje.

Uporaba

- **raziskave**
  - **sipanje nevtronov in nevtronografija** (podobno kot z rentgenskim aparatom lahko z nevtroni slikamo notranjost različnih teles)
  - **reaktorska fizika in tehnika** (študij lastnosti reaktorjev in pomožnih sistemov)
  - **aktivacijska analiza** (z nevtroni naredimo snov radioaktivno in sklepamo na vsebnost in količino različnih elementov)
  - **raziskave ščitenja pred sevanjem**
  - **medicina** (npr. uničevanje tumorjev s pomočjo nevtronov)
  - **materiali** (npr. študij notranje strukture, umetno staranje)
- **proizvodnja radioaktivnih izotopov** (v medicini z njimi ugotavljajo in zdravijo bolezni, v industriji preiskujejo materiale)
- **usposabljanje operaterjev** jedrske elektrarne Krško in drugih strokovnjakov

Basic Data

Operational since 1966.
There are more than 40 reactors of this type in the world.

Manufacturer: General Atomics, USA
Power: 250 kW

Fuel: enriched uranium (up to 20% U-235)

Minimum mass of uranium: 2.3 kg U-235

Moderator: zirconium hydride

Coolant: ordinary water, natural convection

Control rods: 4 boron carbide rods

Safety

The chain reaction automatically stops if the reactor overheats.

Applications

- research
  - neutron scattering and neutronography
  - reactor physics and engineering
  - activation analysis
  - radiation shielding studies
  - medicine
  - materials
- production of isotopes
- nuclear power plant operator training

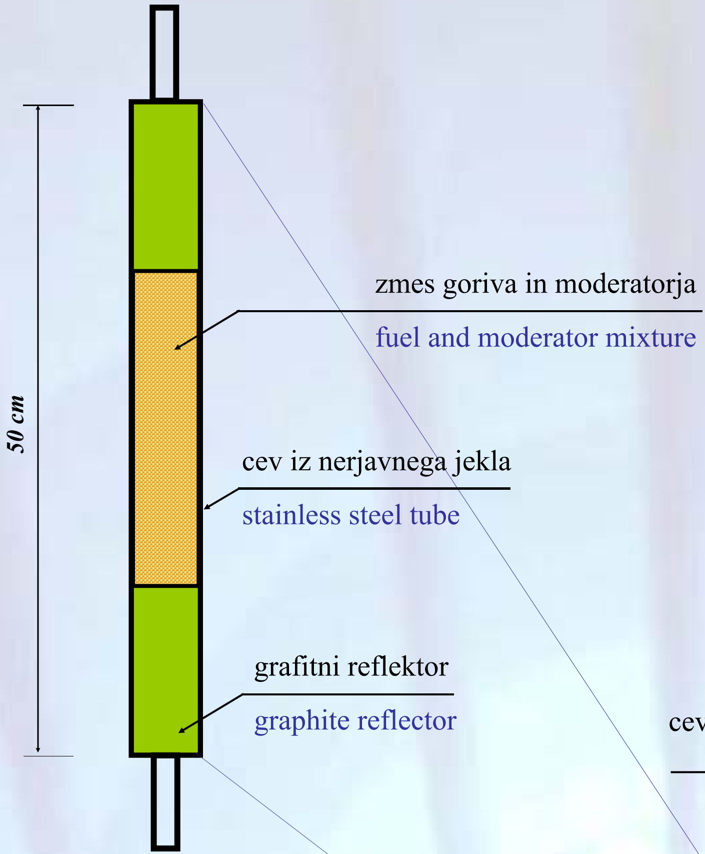
V ozadju je slika pogled v reaktor med ***pulziranjem****, ko moč v nekaj milisekundah zelo naraste.*

In the background is a picture of a ***reactor pulse****, resulting from a strong power increase for a period of a few milliseconds.*

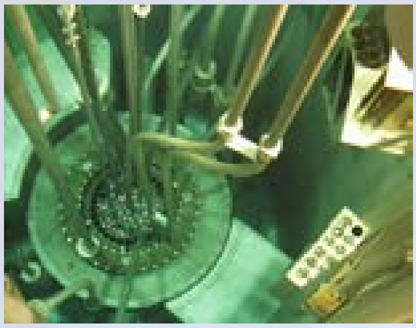
Zasnova reaktorja TRIGA

Design of the TRIGA Reactor

Gorivni element
Fuel element

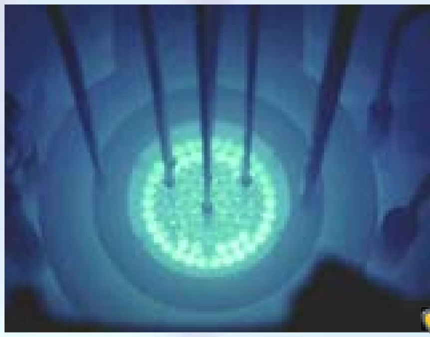


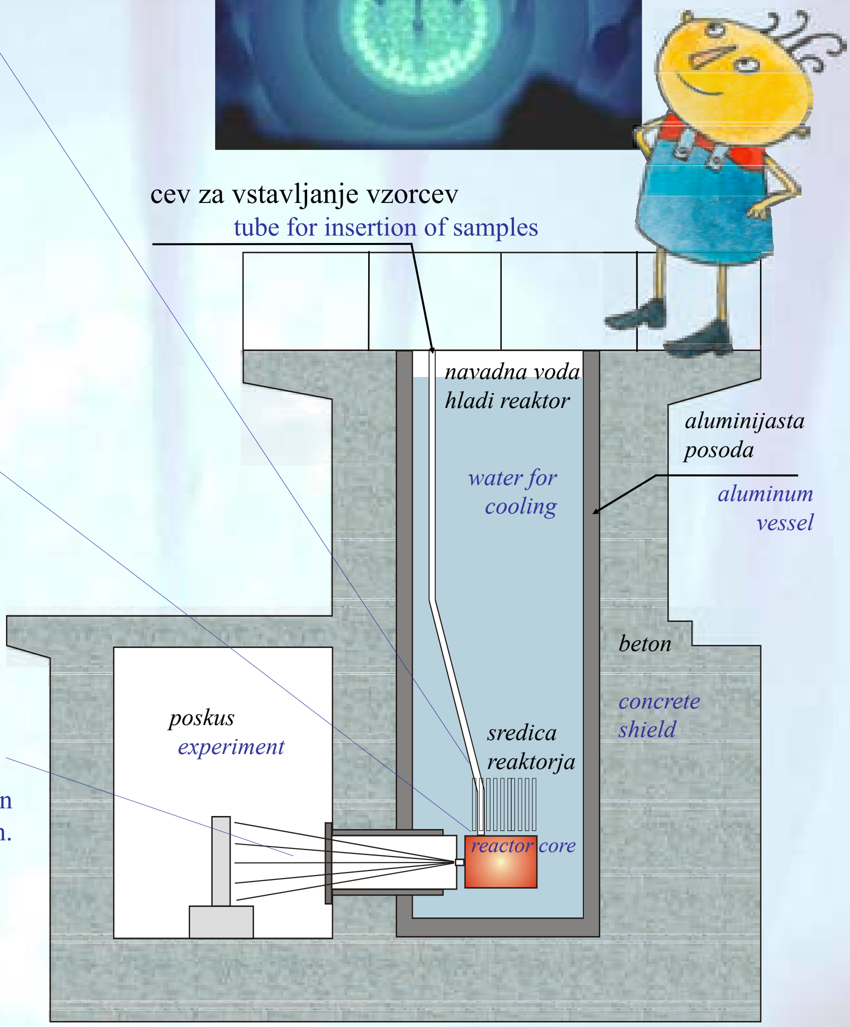
Pogled v reaktor
View from above



Pogled v reaktor med ***pulziranjem****,*
ko moč v nekaj milisekundah zelo naraste.

View of the reactor core ***during a pulse*** *when*
the reactor power sharply increases within milliseconds.





Višek nevtronov, ki niso potrebni za verižno reakcijo, uporabljamo za raziskave in obsevanje.

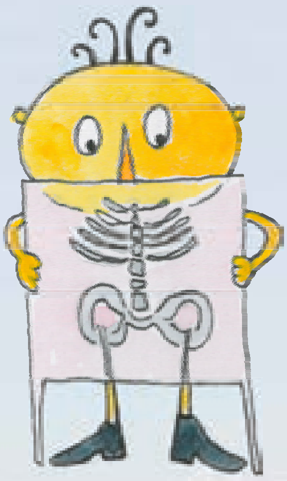
Surplus neutrons that are not necessary for the chain reaction are used for experiments and irradiation.

Prerez reaktorja TRIGA
Cross-section of the TRIGA reactor

Uporaba radioaktivnega sevanja

Uses of Radiation

Medicina
Medicine



Preiskave
Diagnosis

Z **rentgenskimi aparati** zdravniki „vidijo“ notranjost našega telesa.

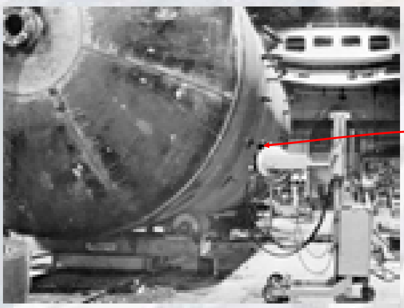
Physicians can “see” inside our body using **X-ray** machines.

Zdravljenje
Treatment

Z obsevanjem lahko **zdravimo raka**.

Cancer can be treated by irradiation.

Industrija
Industry



Ugotavljanje napak v kovinah

Detection of defects in metals

Štetje in tehtanje predmetov in snovi na tekočem traku

Counting and weighing on conveyor belts

In še: merilniki gostote in vlage, strelovodi, odkrivanje napak v kanalizaciji, merjenje nivoja v rezervoarjih, določanje starosti arheoloških najdb, sterilizacija hrane, …

And more: density and moisture meters, lightning conductors, leak detection in sewage systems, level measurements in tanks, age determination, sterilization of food, etc.

Znanost
Science

Raziskave na različnih področjih, ki nam lahko v kratkem ali daljšem časovnem obdobju koristijo v vsakdanjem življenju.

Research in different fields leading to better everyday life in the near or more distant future.

Jedrska elektrarna Krško in okolje

Krško Nuclear Power Plant and the Environment

Jedrska elektrarna med normalnim obratovanjem minimalno onesnažuje okolje.

During normal operation, the nuclear power plant causes almost no pollution of the environment.

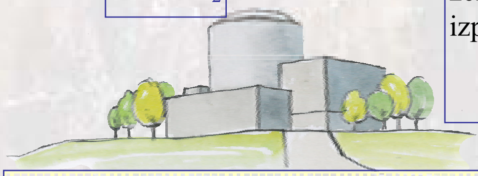
nič NO_x
no NO_x

nič SO_2
no SO_2

nič pepela
no ashes

nič CO_2
no CO_2

zelo malo radioaktivnih izpustov
very few radioactive effluents



Prispevek elektrarne k dozi sevanja posameznika je okrog **0,001 mSv na leto**, kar je le okoli 1/3000 naravne doze.

The nuclear power plant contributes about **0.001 mSv** to the annual dose which represents only around 1/3000 of the natural dose.

Merilna postaja

Measuring station

Radioaktivne pline pred izpustom v atmosfero nekaj let zadržijo v posebnih posodah. V tem času njihova radioaktivnost upade.

Radioactive gases are held in special tanks for several years, and during this time their radioactivity decreases.

Nivoje sevanja na Krškem polju stalno merijo na več mestih v okolici elektrarne.

Radiation levels are permanently measured at a number of locations around Krško NPP.

Edini merljivi vpliv jedrske elektrarne Krško na okolje je segrevanje savske vode za nekaj °C. Enak vpliv bi imela primerljiva termoelektrarna.

The only measurable environmental impact of the Krško NPP is warming of the river Sava by a few °C. A conventional thermal power plant would have the same impact.

Jedrska varnost

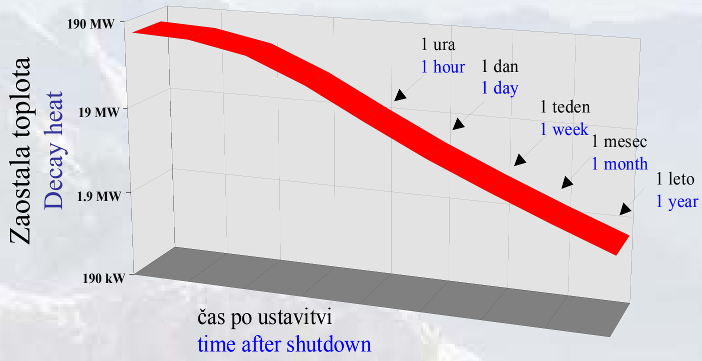
Nuclear Safety

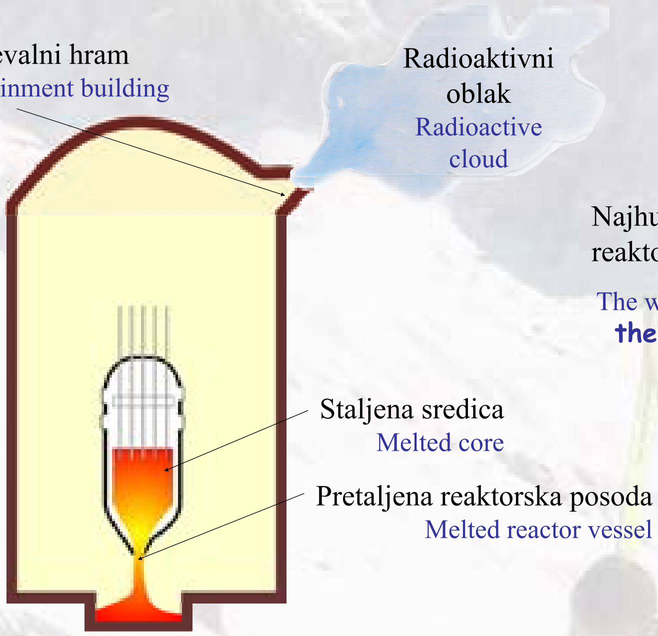
Kaj je v jedrski elektrarni nevarno?

- V reaktorju nastajajo **radioaktivne snovi**, ki so nevarne živim bitjem.
- Jedrsko gorivo tudi po ustavitvi verižne reakcije zaradi radioaktivnega razpada sprošča **zaostalo toploto.**

What dangers exist in a NPP?

- During reactor operation, **radioactive substances** dangerous for living beings are produced.
- Even after the chain reaction is stopped, **decay heat** is released from the nuclear fuel.





Najhujše posledice bi imelo **taljenje sredice** reaktorja in sproščanje radioaktivnih snovi v ozračje.

The worst-case accident scenario would be a **meltdown of the reactor** core and a release of radioactive substances into the environment.

Če imamo

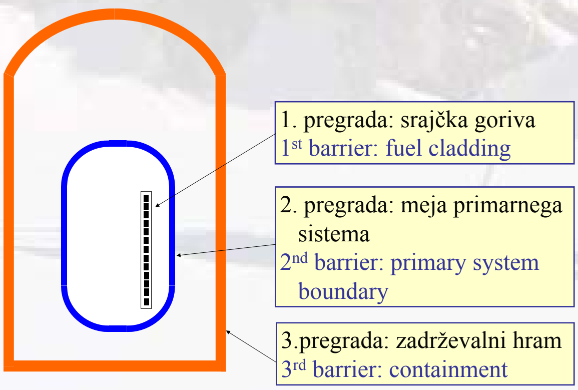
- **nadzor nad močjo** reaktorja,
- zagotovljeno **hlajenje goriva** in
- **zadrževanje radioaktivnih** snovi,

je jedrska elektrarna **v varnem stanju.**

When

- the reactor **power is under control,**
- **cooling of the fuel** is ensured, and
- **confinement of radioactive substances** is also ensured,

the nuclear power plant **is in a safe condition.**



Tri neodvisne varnostne pregrade preprečujejo pobeg radioaktivnih snovi v okolje.

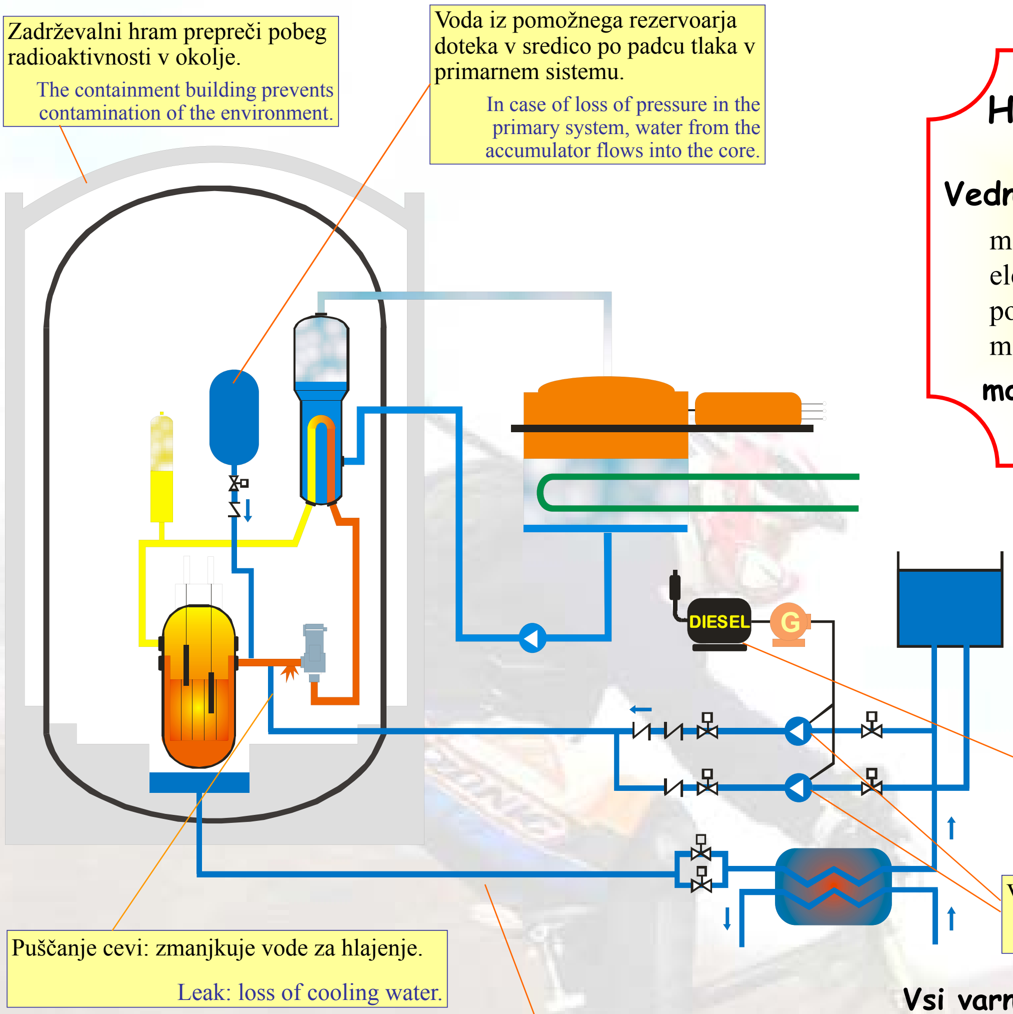
Three independent safety barriers prevent the escape of radioactive substances into environment.

Varnostni sistemi

blažijo posledice okvar in preprečijo onesnaženje okolja.

Safety Systems

mitigate the consequences of an accident and prevent contamination of the environment.



Hlajenje, hlajenje, hlajenje ...

Vedno,

med obratovanjem, ali če je elektrarna ustavljena,
pozimi ali poleti,
med nevihto ali med potresom,

moramo hladiti sredico !

Cooling, cooling ...

The reactor core must be always cooled !

Sistemi in scenarij na skici le prikazujejo načela delovanja. Resnični sistemi so bolj zapleteni.

Systems and scenarios illustrated here are purely for demonstration purposes. Real systems are more complicated.

Vsi varnostni sistemi so podvojeni. Če se pokvari ena črpalka, druga še vedno zagotavlja pretok vode.

All safety systems are duplicated. If one pump fails, another one supplies sufficient water instead.

Več kot polovica investicije v jedrsko elektrarno je investicija v varnost.

More than one-half of the total investment in the NPP is in nuclear safety.

Varnostna kultura

Pomembnejša od tehničnih naprav je **varnostna kultura** zaposlenih v jedrskem objektu:

- Vsa dela so pomembna za varnost.
- Kar koli narediš, pomisli, kako bo to vplivalo na varnost.
- Nikoli ne bodi prepričan, da se ne moreš zmotiti.
- Vedno moraš dvomiti:
  - ⇒ Kaj, če sem kaj spregledal?
  - ⇒ Bi lahko to naredil še bolje?

Safety Culture

More important than the technical facilities of the nuclear power plant is the **safety culture** of employees:

- All activities are important for safety.
- Whatever you do, consider how it will impact on safety.
- Never allow yourself to become convinced that you cannot make a mistake.
- Never become complacent – ask:
  - ⇒ Have I overlooked anything?
  - ⇒ Could that have been done better?

Otok treh milj (ZDA)

Three Mile Island (USA)

Pogled na elektrarno

General view of the plant

Nesreča se je zgodila 28. marca 1979 na Otoku treh milj v ameriški zvezni državi Pensilvanija.

This accident occurred on 28 March 1979, at Three Mile Island in Pennsylvania.

Potek nesreče

- Skozi zataknjen varnostni ventil je začela puščati reaktorska hladilna voda.
- Operaterji niso pravilno ocenili nezgode in so izklopili dobro delujoč varnostni sistem za zasilno hlajenje sredice.
- Izguba reaktorskega hladila je povzročila taljenje sredice.
- Ostanke sredice je zadržala nepoškodovana reaktorska posoda.
- V zadrževalni hram je ušel le majhen del radioaktivnih snovi.
- Nesreča ni imela radioloških učinkov na okolje in prebivalstvo.

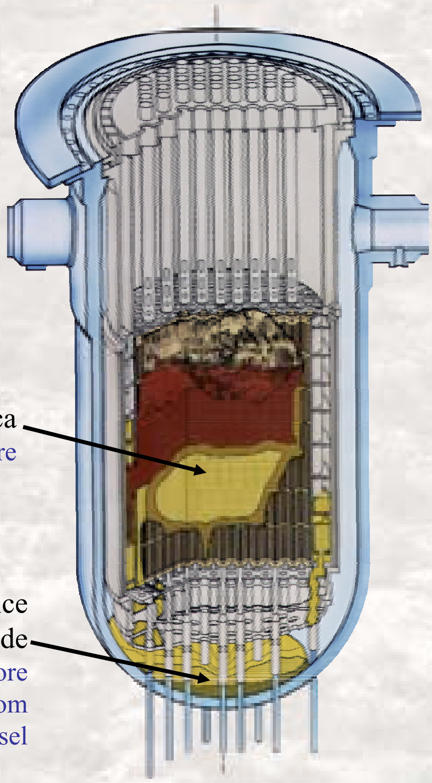
Course of the accident

- The accident started with an equipment failure which caused a loss of reactor coolant through a partly-opened safety valve.
- The operators misinterpreted the accident and switched off the properly-working emergency core cooling system.
- The loss of reactor coolant caused core melting.
- The undamaged reactor vessel contained the damaged core.
- A small amount of radioactive material escaped into the containment building.
- The accident had no radiological effects on the environment or the population.

Posledice nesreče na Otoku treh milj so bile neprimerljivo blažje kot v Černobilu ali Fukušimi, ker je zadrževalni hram opravil svojo nalogo.

Consequences of the TMI accident were incomparably milder than at Chernobyl or Fukushima, because the containment fulfilled its function.

Staljena sredica v reaktorju TMI
Melted core in the TMI reactor



Kasneje so v vseh podobnih elektrarnah po svetu (tudi v Krškem) izvedli vrsto ukrepov, da se podobna nesreča ne bi ponovila.

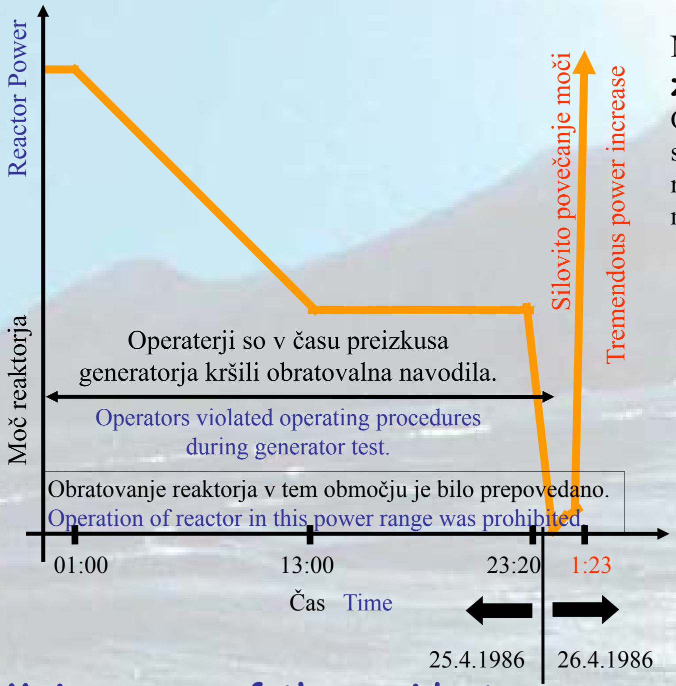
In all similar plants in the world, appropriate measures were taken to prevent a similar accident from happening again.

Černobil (Sovjetska zveza / Ukrajina)

Chernobyl (Soviet Union / Ukraine)

26. aprila 1986 se je v elektrarni Černobil 4 v Ukrajini zgodila najhujša jedrska nesreča do sedaj.

On 26 April 1986, the worst nuclear accident so far occurred at the Chernobyl 4 NPP in the Ukraine.



Neposreden povod za nesrečo je bilo **zavestno kršenje predpisanih postopkov**.
Operaterji so pripeljali reaktor v nestabilno območje, moč se je skokovito povečala, sledila je eksplozija in požar grafita, ki je radioaktivne snovi ponesel daleč naokrog. Elektrarna v Černobilu ni imela zadrževalnega hrama.

The direct cause of the accident was a **violation of operating procedures**.
The operators brought the reactor into an unstable state, the power drastically increased, this caused an explosion and fire in the graphite moderator, releasing large quantities of radioactive material over a wide area. The Chernobyl NPP had no containment.

Glavna vzroka nesreče:

- **zasnova** reaktorja
- **slaba varnostna kultura**

Main causes of the accident:

- **design** of the reactor
- **poor safety culture**

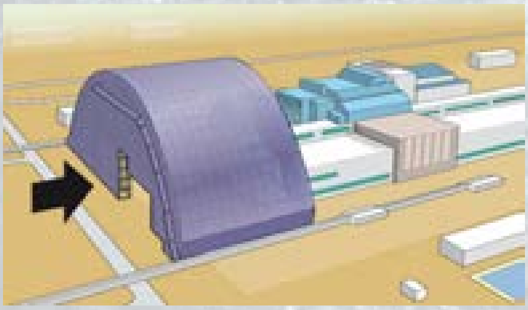
> Tlačnovodni reaktorji (npr. NEK) zaradi svoje zasnove sploh ne morejo priti v tako nestabilno stanje kot je bilo v Černobilu pred nesrečo.
>
> The design of PWRs does not allow the reactor to become similarly unstable as was the case in Chernobyl.

Preko ponesrečenega reaktorja je bil zgrajen **»Sarkofag«.**

A **"Sarcophagus"** was built over the ruined reactor.

Preko poškodovanega **sarkofaga** bo zgrajena nova zaščitna zgradba.

A new protection building will be built over the degraded **Sarcophagus**.



Posledice nesreče

- 47 ljudi je umrlo.
- Približno 4000 otrok je zbolelo za rakom na ščitnici, 9 jih je umrlo, ostale so pozdravili.
- Ocenjujejo, da bo med skupno 600.000 reševalci in prebivalci najbolj kontaminiranih področij še približno 4000 ljudi umrlo za rakom in levkemijo zaradi sevanja. To je približno 3 % smrti zaradi spontanega raka, ki ni povezan s černobilskim sevanjem.
- Razen znotraj 30-kilometrskega izključitvenega območja so nivoji sevanja večinoma normalni.

Consequences of the accident

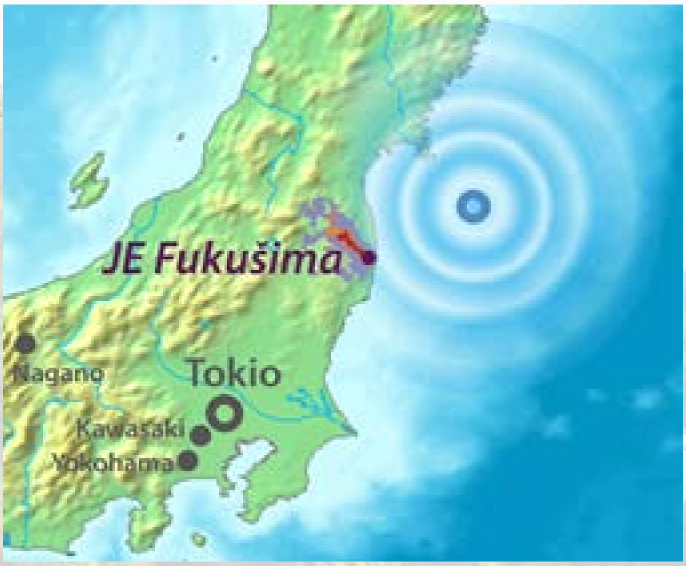
- 47 people died.
- About 4000 cases of thyroid cancer among children were diagnosed, 9 died, others were cured.
- Among around 600,000 emergency workers and residents of the most contaminated areas about 4000 deaths from radiation-induced cancer and leukemia are expected. This is about 3% of the spontaneous cancers not caused by Chernobyl radiation.
- Except in the 30-kilometre exclusion area, the radiation levels are again mostly normal.

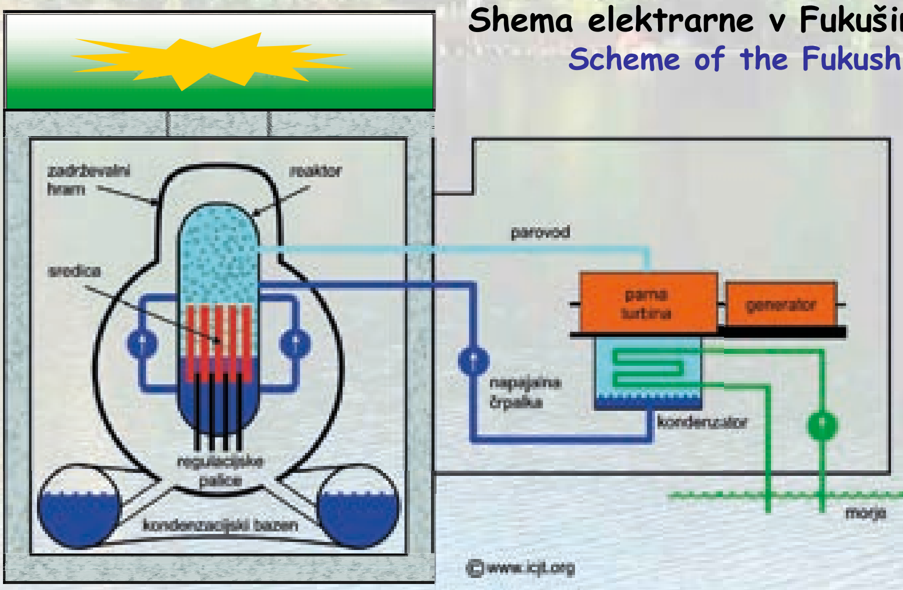
Fukušima (Japonska)

Fukushima (Japan)

11. marca 2011 je po potresu 9 stopnje izjemen cunami (8 m višji od projektno predvidenega) poplavil jedrsko elektrarno Fukušima Daiči (6 vrelnih reaktorjev) in onesposobil njene varnostne sisteme.

On 11 March 2011, an exceptional tsunami (8 m higher than considered in the design) following a magnitude 9 earthquake flooded the Fukushima Daiichi Nuclear Power Plant (6 BWR units) and disabled the safety systems.





Shema elektrarne v Fukušimi

Scheme of the Fukushima power plant

Trije reaktorji so ostali brez hlajenja, ob pregrevanju goriva je nastal vodik, ki je povzročil eksplozijo v reaktorski stavbi. Gorivo je bilo zaradi pregrevanja poškodovano, sproščale so se radioaktivne snovi.

Three reactors lost cooling, fuel overheated and produced hydrogen which exploded in the reactor building. The fuel was damaged and released radioactive materials.

Posledice nesreče

- nihče ni umrl zaradi sevanja
- 70.000 evakuiranih iz 20-km kroga (pred sprostitvijo radioaktivnosti)
- del evakuiranih področij je že varnih za normalno bivanje

Consequences of the accident

- No victims due to radiation
- 70,000 evacuated from a 20 km radius before radioactivity release
- Part of the evacuated areas is already safe for normal life

Nauki nesreče

V svetu in v Sloveniji so bile izvedene analize odpornosti na ekstremne dogodke in izboljšave varnostnih lastnosti.

Lessons learned

Resilience against extreme natural events was analysed in NPPs of the world ("stress tests") and additional safety features were introduced.

Odpadki in radioaktivni odpadki

Waste and Radioactive Waste

Pri skoraj vseh dejavnostih nastajajo tudi odpadki.
Radioaktivni odpadki so posebna skupina nevarnih odpadkov.

Almost every activity generates waste.
Radioactive waste is a special kind of hazardous waste.

Viri odpadkov:
Sources of waste:

- gospodinjstva — households
- industrija — industry
- gradbeništvo — construction
- rudarjenje — mining
- medicina — medicine
- kmetijstvo — farming
- ...

Nevarni odpadki:
Hazardous waste:

- strupeni — toxic
- kužni — infectious
- vnetljivi — flammable
- jedki — corrosive
- eksplozivni — explosive
- radioaktivni — radioactive
- ...

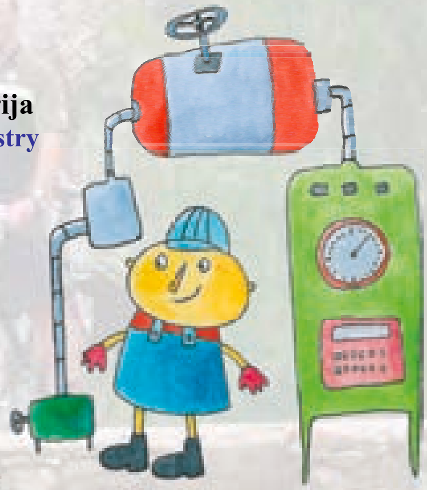
Količina vseh vrst odpadkov ves čas narašča.
The amount of all kinds of waste is constantly increasing.

Viri radioaktivnih odpadkov

Sources of radioactive waste

Jedrske elektrarne
Nuclear Power Plants

Industrija
Industry



Medicina
Medicine

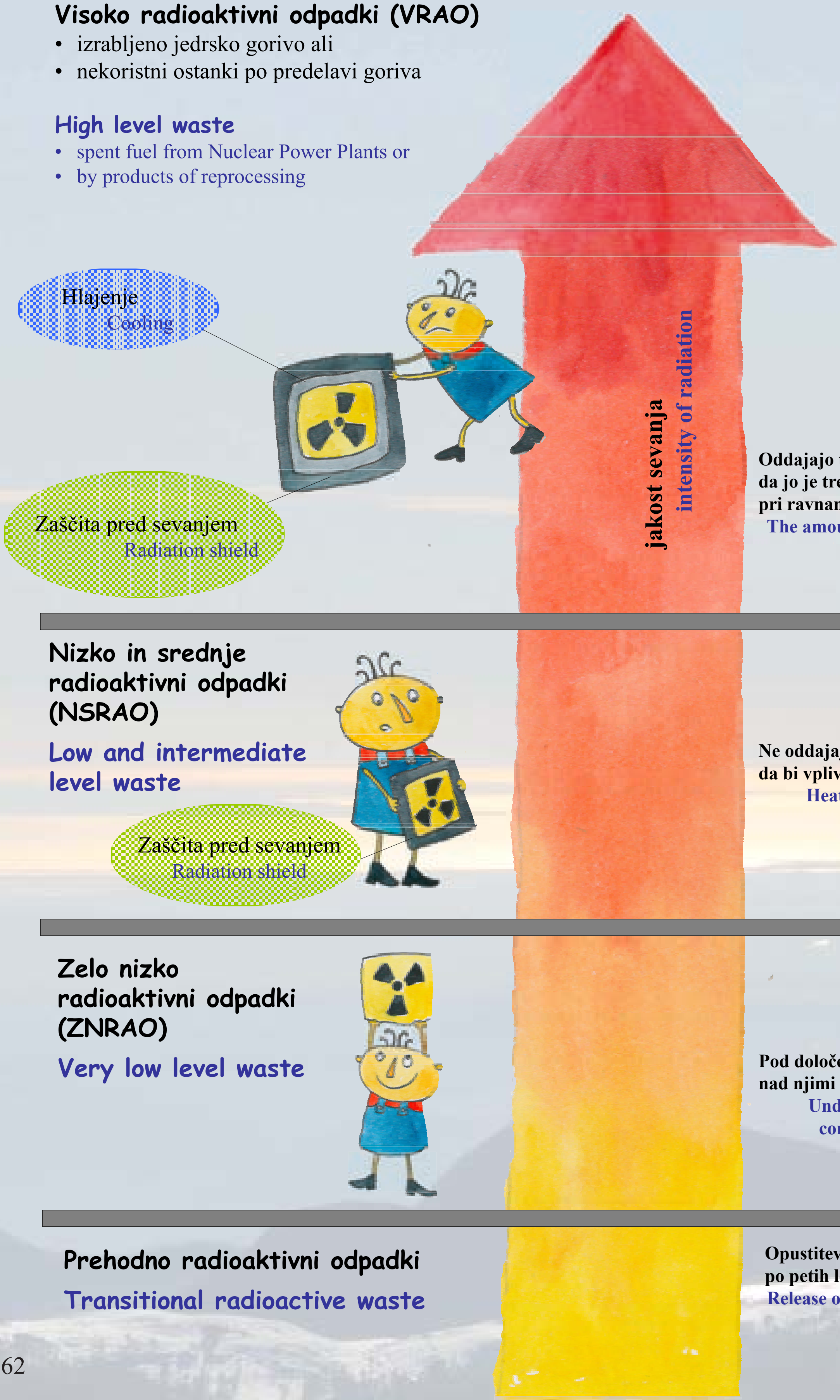
Raziskave
Research

Vrste radioaktivnih odpadkov

Types of Radioactive Waste

Visoko radioaktivni odpadki (VRAO)
- izrabljeno jedrsko gorivo ali
- nekoristni ostanki po predelavi goriva

High level waste
- spent fuel from Nuclear Power Plants or
- by products of reprocessing



Oddajajo toliko toplote, da jo je treba upoštevati pri ravnanju z njimi.
The amount of heat generated has to be considered.

Nizko in srednje radioaktivni odpadki (NSRAO)

Low and intermediate level waste

Ne oddajajo toliko toplote, da bi vplivala na ravnanje z njimi.
Heat generation is negligible.

Zelo nizko radioaktivni odpadki (ZNRAO)

Very low level waste

Pod določenimi pogoji se nad njimi lahko opusti nadzor.
Under certain conditions control can be released.

Prehodno radioaktivni odpadki

Transitional radioactive waste

Opustitev nadzora mogoča po petih letih začasne hrambe.
Release of control after 5 years of temporary storage.

Viri radioaktivnih odpadkov v Sloveniji

Sources of Radioactive Waste in Slovenia

Visoko radioaktivni odpadki

High level waste

Nizko in srednje radioaktivni odpadki

Low & intermediate level waste

Skladiščenje v NEK:

Storage in Krško NPP:

Bazen za izrabljeno gorivo
(6 m^3/leto)

Spent fuel pool
(6 m^3/year)

Sodi z NSRAO
(35 m^3/leto)

Drums with low & intermediate level waste
(35 m^3/year)

Nizko in srednje radioaktivni odpadki

Low & intermediate level waste

1 – 2 m^3/leto

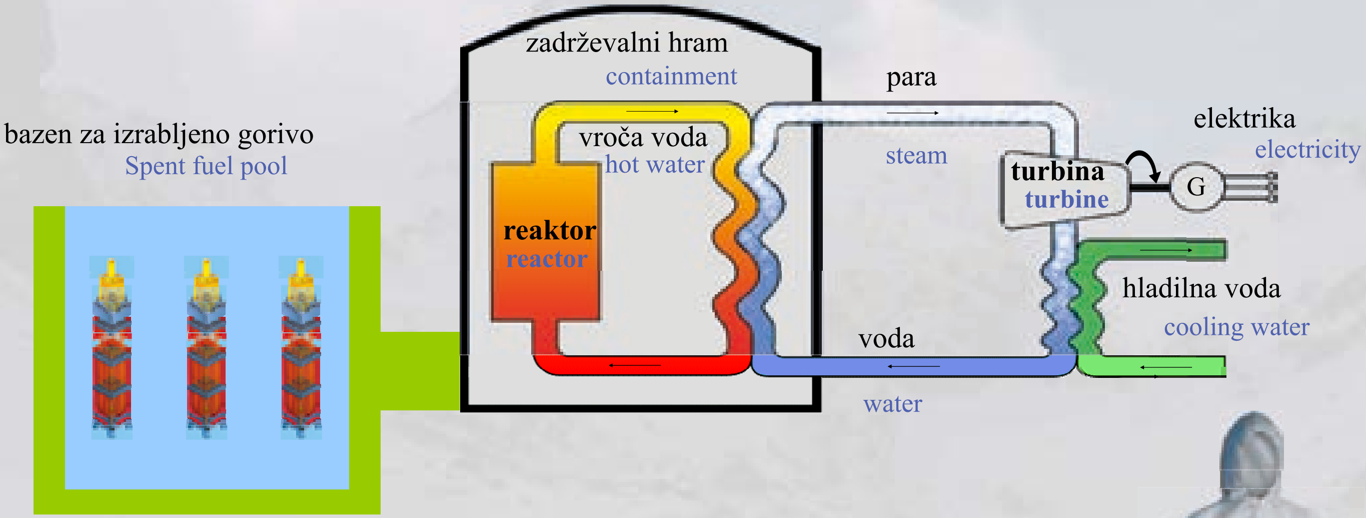
1 – 2 m^3/year

Centralno skladišče RAO
Brinje pri Ljubljani

Central Interim Storage Facility
in Brinje near Ljubljana

Radioaktivni odpadki v jedrski elektrarni

Radioactive Waste in a Nuclear Power Plant

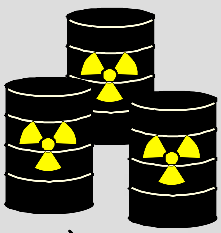


Visoko radioaktivni odpadki – VRAO
(izrabljeni gorivni elementi)

High level waste – HLW
(spent fuel elements)

Nizko radioaktivni odpadki – NRAO
nastajajo večinoma
med vzdrževalnimi deli

Low level waste – LLW
is mainly
generated during
maintenance work



Srednje radioaktivni odpadki – SRAO
(odpadki iz čistilnih naprav)

Intermediate level waste – ILW
(waste from clean-up systems)

Količina odpadkov NEK v m^3:

Waste from Krško NPP in m^3:

	NSRAO LLW & ILW	VRAO HLW
obratovanje (40 let) operation (40 years)	3 500	250

Odlaganje radioaktivnih odpadkov

Disposal of Radioactive Waste

Radioaktivne odpadke imamo, zato moramo zanje poskrbeti. Obstaja več načinov njihovega odlaganja:

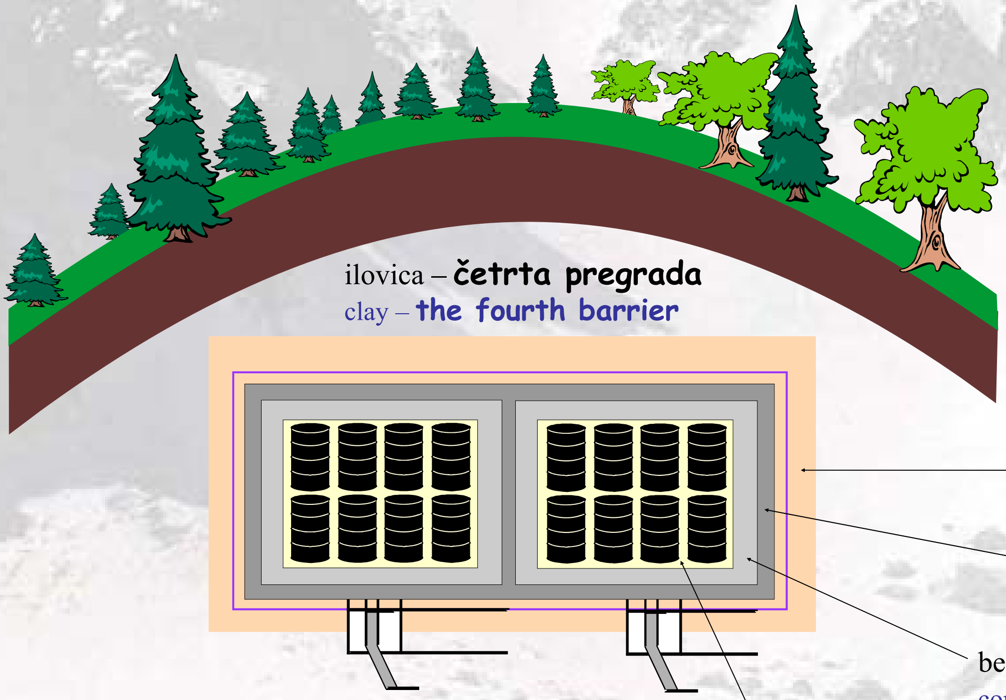
- pri-površinsko odlagališče (površinsko ali podzemno)
- globoko podzemno odlagališče

Since radioactive waste exists, we need to take care of it. There are several types of repository:

- near surface types
- geological repository

Načelo zaporednih pregrad

The Multiple Barrier Principle



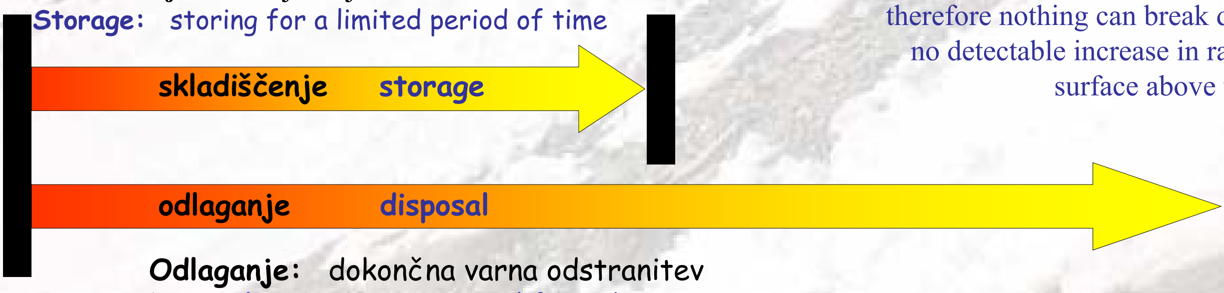
Suho odlaganje:
Voda je glavni možni prenašalec radioaktivnih snovi, zato na lokaciji odlagališča ne sme biti vodnih tokov.

Dry disposal:
Water is the biggest threat as a carrier of radioactive substances, therefore the repository should be dry or at least without water outflow.

V odlagališču se nič ne dogaja, zato se tudi ne more nič pokvariti. Na površju nad odlagališčem ni zaznati povišanih doz sevanja.

There is nothing going on in the repository, therefore nothing can break down. There is no detectable increase in radiation on the surface above the repository.

Skladiščenje: shranjevanje za določeno dobo
Storage: storing for a limited period of time



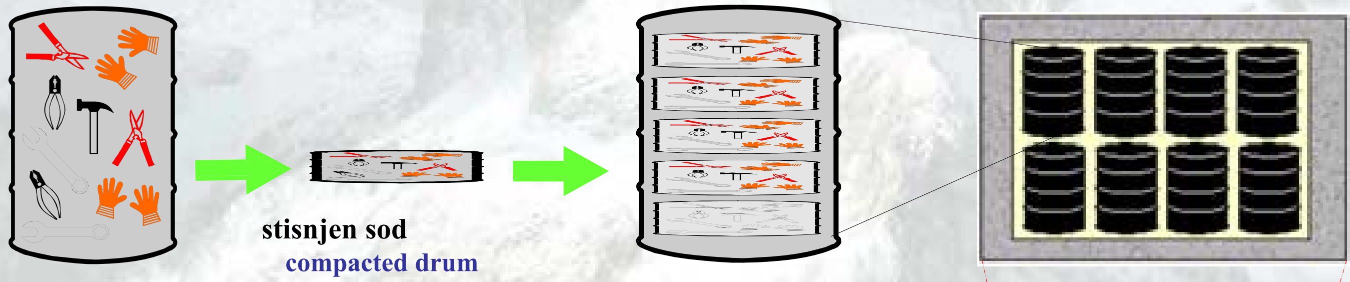
Odlaganje: dokončna varna odstranitev
Disposal: permanent removal from the environment

Odlaganje nizko in srednje radioaktivnih odpadkov

Disposal of Low and Intermediate Level Waste

Priprava NSRAO pred odlaganjem

Treatment and conditioning of low and intermediate level waste

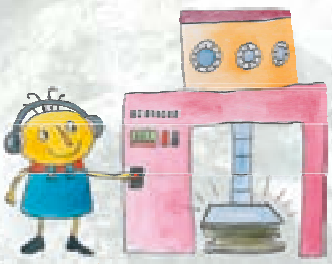


200 litrski sod
200 litre drum

stisnjen sod
compacted drum

večji sod (površnik)
bigger drum (overpack)

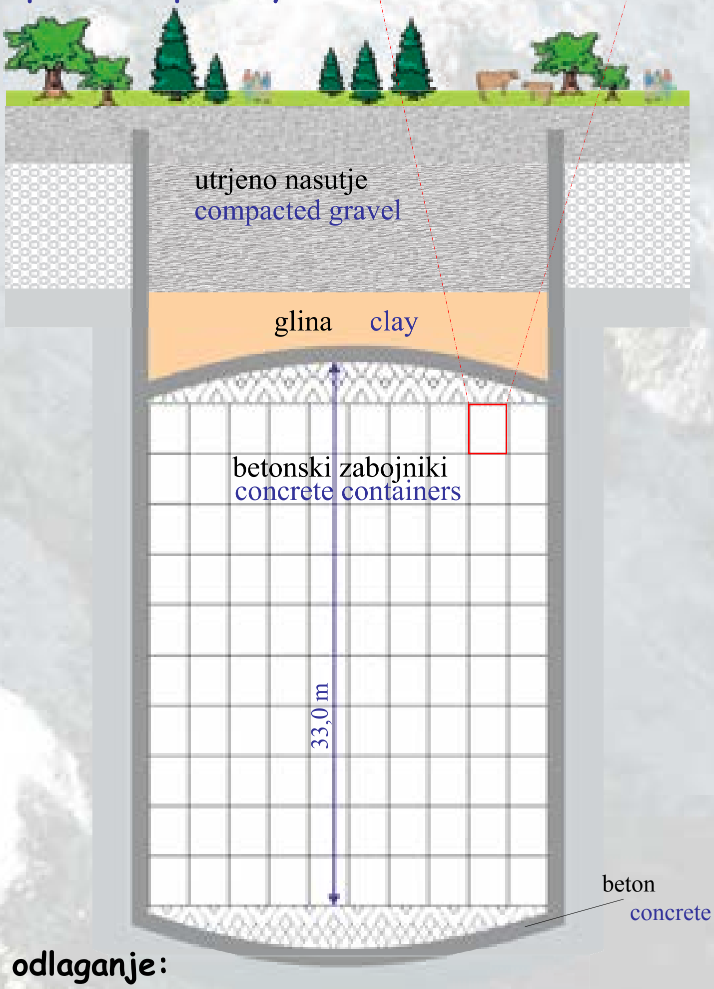
betonski zabojnik
concrete container



stiskanje sodov v Nuklearni elektrarni Krško
drum compaction at Krško NPP

Prerez načrtovanega odlagališča NSRAO v Vrbini – Krško

Cross section of the planned repository for LILW in Vrbina – Krško



Priprava SRAO pred odlaganjem

Treatment and conditioning of intermediate level waste

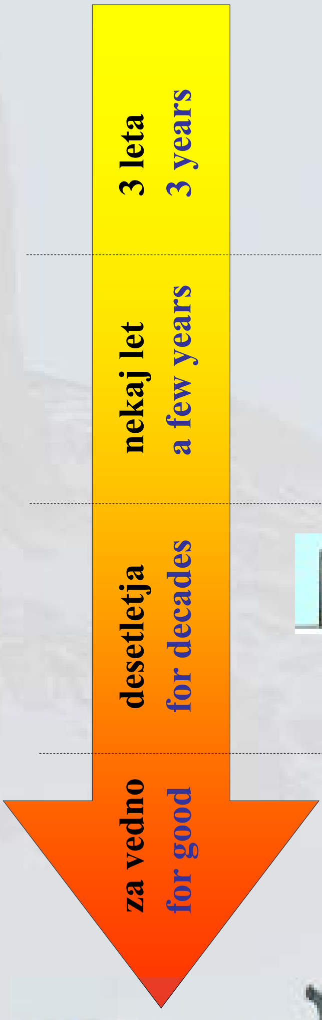
pred odlaganjem odpadke ustrezno pripravimo
waste has to be conditioned before disposal

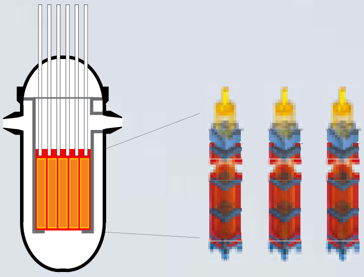
Nasičeno odlaganje:
Voda je prisotna v odlagališču, vendar umetne in naravne pregrade preprečujejo njeno gibanje.

Saturated disposal:
Water is present in the repository, but engineering and natural barriers prevent its movement.

Ravnanje z visoko radioaktivnimi odpadki

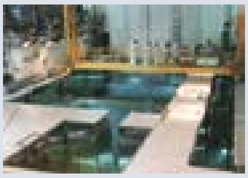
High Level Waste Management



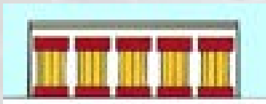


GORIVO V REAKTORJU
FUEL IN REACTOR

Bazen za izrabljeno gorivo v elektrarni
Spent fuel pool



SKLADIŠČENJE V ELEKTRARNI
STORAGE ON SITE of NPP

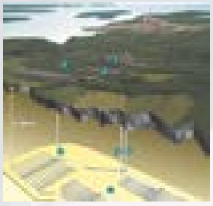


Suho skladišče
Dry storage

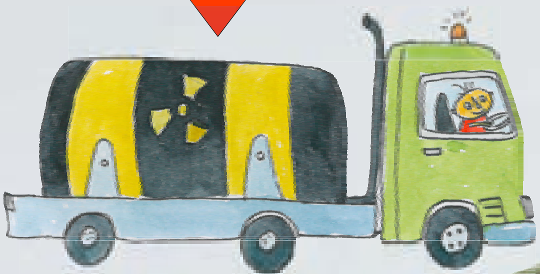
Predelava goriva
Fuel reprocessing

PREHODNO SKLADIŠČENJE
INTERIM STORAGE

Globoko podzemno odlagališče
Geological repository



ODLAGANJE
DISPOSAL



Pri suhem skladiščenju se zabojnik in gorivo hladita z zrakom. V takem zabojniku je gorivo lahko več desetletij. To je najbolj verjetna prehodna rešitev za Slovenijo.

In dry storage the cask and nuclear fuel are cooled by the natural circulation of air. The fuel may be stored in casks for several decades. This is the most probable solution for interim storage of spent fuel in Slovenia.

Enaki zabojniki kot za suho skladiščenje se uporabljajo tudi za prevoz izrabljenega goriva. Zdržijo tudi najhujše možne prometne nesreče, kot npr. na sliki, kjer je prikazano poskusno trčenje vlaka z zabojnikom.

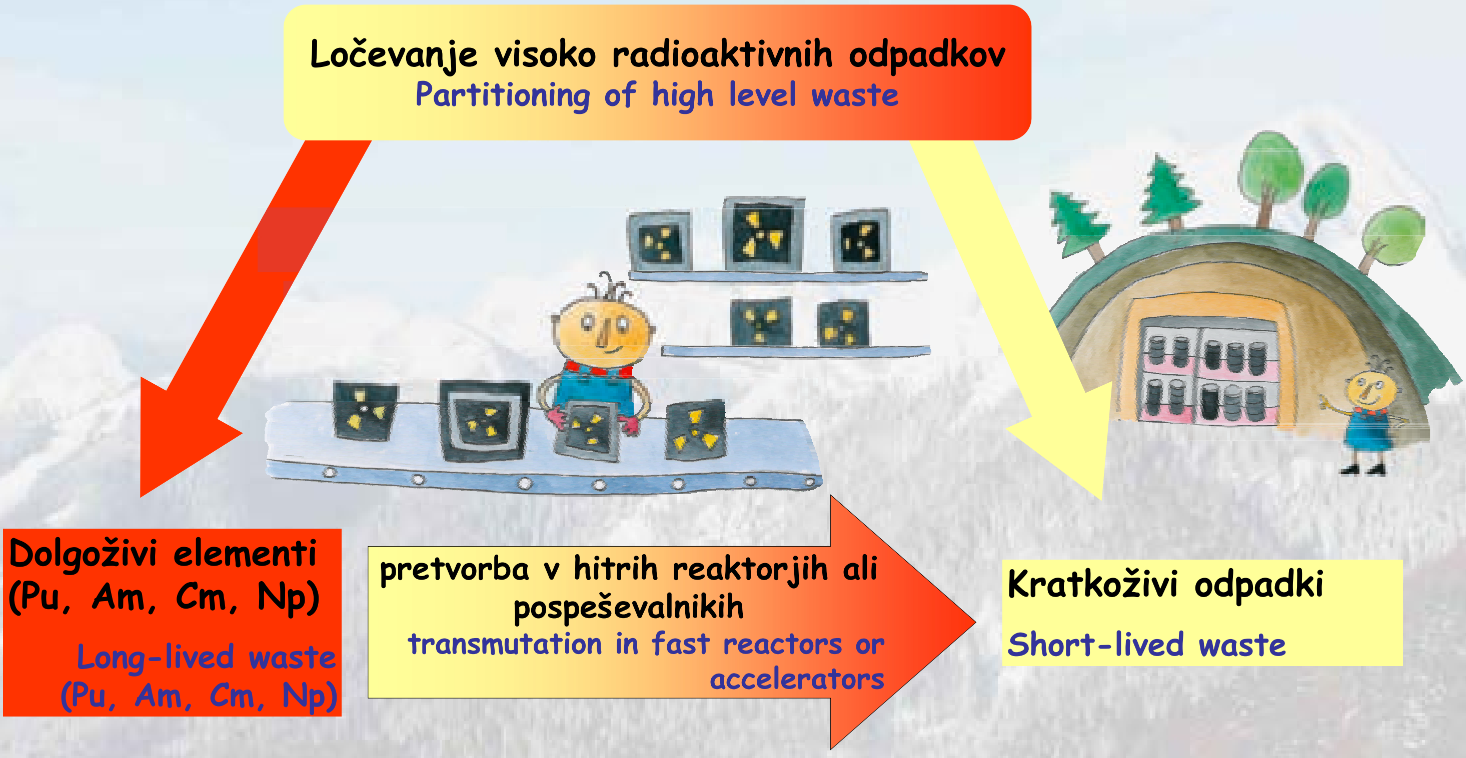
The same casks as for dry storage can be used for transport of spent fuel as well. The casks are designed to survive the worst possible accidents, such as collision with a train shown in the picture.

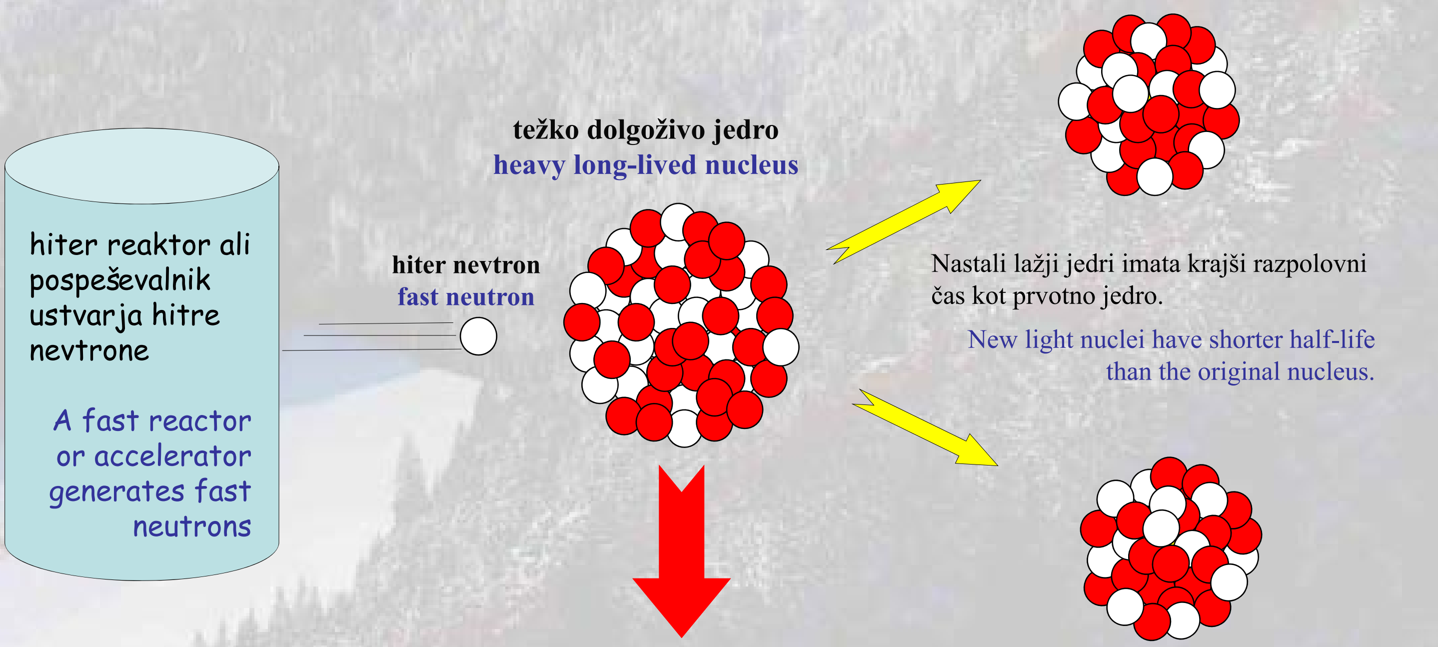
Ločevanje in pretvorba

Partitioning and Transmutation

Dolgožive elemente plutonij (Pu), americij (Am), neptunij (Np) in kirij (Cm) **izločimo** iz visoko radioaktivnih odpadkov ter jih z **jedrskimi reakcijami pretvorimo** v kratkožive.

Long-lived elements plutonium (Pu), americium (Am), neptunium (Np) and curium (Cm) are separated from the high-level radioactive waste and converted by nuclear reactions into short-lived elements.





Del energije se sprosti v obliki **uporabne toplote**.

Part of the energy released is converted into **useful heat**.

Abecedno kazalo

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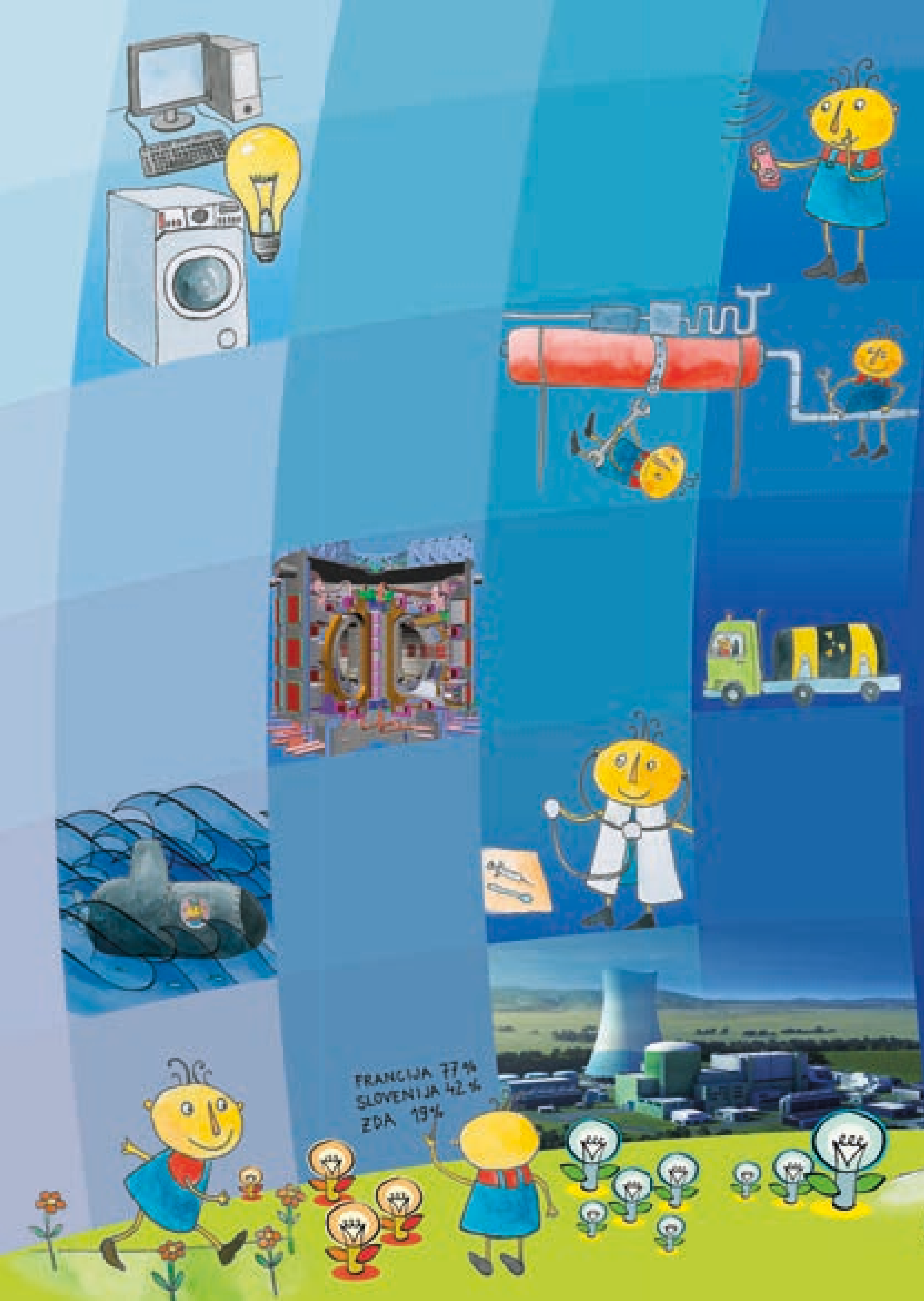
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