Environmental aspects of nuclear energy

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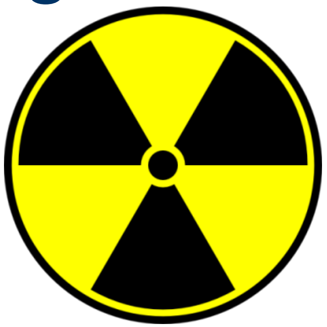
Nuclear energy in general

- **production of fissile materials**
- production of electricity in nuclear power plants
- release of nuclear energy from the atomic nucleus
- chain fission in nuclear fuel
- accompanying phenomenon - **ionizing radiation**



Production of fissile materials

Mining in the open pit mines:

- extraction in open pit mines very similar to coal production
- generally the least impact on the environment with respect to other methods of mining
- extraction of nuclear fuel is just as harmful as other methods of mining
- intervention in the landscape depends on the amount of ore and yield (percentage of) nuclear fuel

Rössing, Namibia

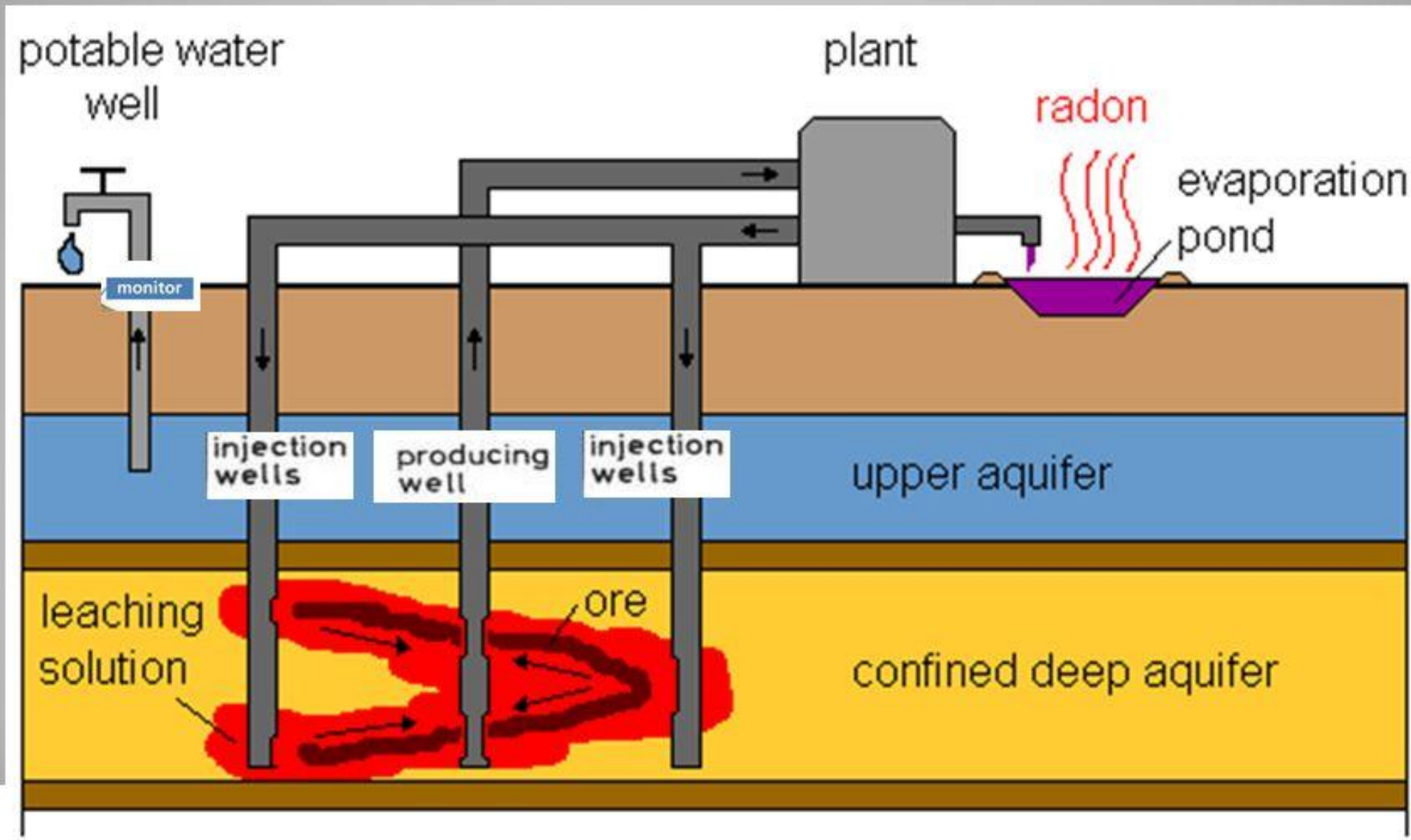
Brown coal production – chateau Jezeří

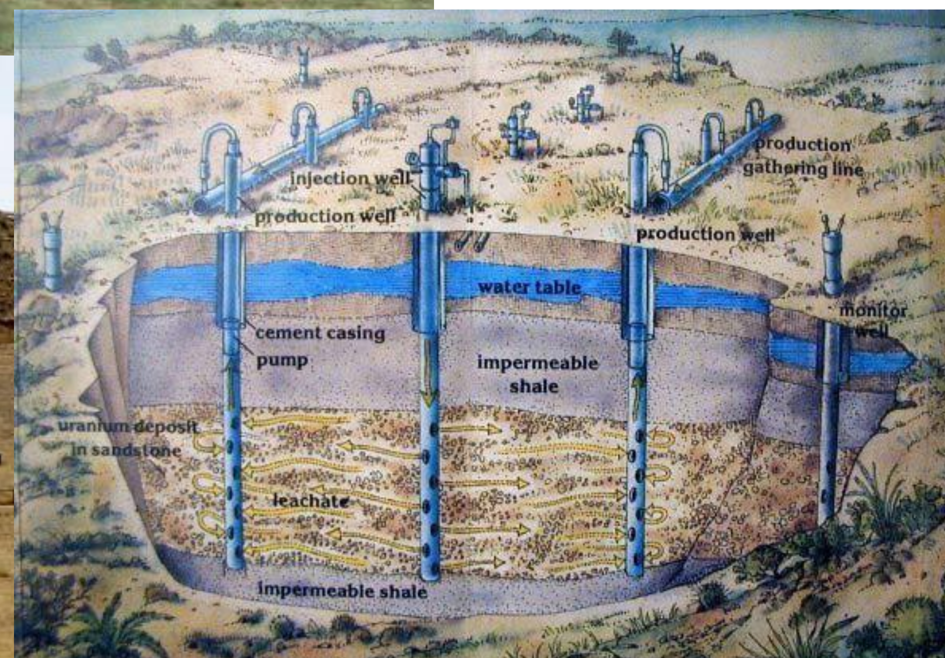
Uranium production – Rožná

In Situ Leaching

- **In situ leaching** (ISL), also known as solution mining, or **in situ recovery** (ISR) in North America, involves leaving the ore where it is in the ground, and recovering the minerals from it by dissolving them and pumping the pregnant solution to the surface where the minerals can be recovered.
- Consequently there is little surface disturbance and no tailings or waste rock generated.
- However, the orebody needs to be permeable to the liquids used, and located so that they do not contaminate groundwater away from the orebody.
- In 2015, 48% of world uranium mined was from ISL operations. Most uranium mining in the USA, Kazakhstan and Uzbekistan is now by in situ leach methods, also known as in situ recovery (ISR).
- ISL mining of uranium is undertaken in Australia, China, and Russia as well.
- In USA ISL is seen as the most cost effective and environmentally acceptable method of mining, and other experience supports this.

In Situ Leaching




injection well
production well
production gathering line
production well
water table
monitor well
cement casing
pump
impermeable shale
uranium deposit in sandstone
leachate
impermeable shale

In Situ Leaching

Spill after pipe failure

The advantages of this technology are:

- the reduced hazards for the employees from accidents, dust, and radiation,
- the low cost;
- no need for large uranium mill tailings deposits.

The disadvantages of the in-situ leaching technology are:

- the risk of spreading of leaching liquid outside of the uranium deposit, involving subsequent groundwater contamination,
- the unpredictable impact of the leaching liquid on the rock of the deposit,
- the impossibility of restoring natural groundwater conditions after completion of the leaching operations.
- Moreover, in-situ leaching releases considerable amounts of radon, and produces certain amounts of waste slurries and waste water during recovery of the uranium from the liquid.

In Situ Leaching

- In the case of **Königstein (Germany)**, a total of 100,000 tonnes of sulfuric acid was injected with the leaching liquid into the ore deposit. At present, 1.9 million m^3 of leaching liquid are still locked in the pores of the rock leached so far.
- Groundwater impact is much larger at the **Czech Republic**'s in-situ leaching site of **Stráž pod Ralskem**: 28.7 million m^3 of contaminated liquid is contained in the leaching zone, covering an area of 5.74 km^2. This zone contains a total of 1.5 million tonnes of sulphate, 37,500 tonnes of ammonium, and others. In addition to the chemicals needed for the leaching operation (including 3.7 million tonnes of sulfuric acid, among others), 100,000 tonnes of ammonium were injected; they were a waste product resulting from the recovery of uranium from the leaching liquid.
  Moreover, the contaminated liquid has spread out beyond the leaching zone horizontally and vertically, thus contaminating another area of 28 km^2 and a further 235 million m^3 of groundwater.
- In **Bulgaria**, a total of 2.5 million tonnes of sulfuric acid was injected into the ore deposits exploited by in-situ leaching. It is estimated that about 10% of the surface area used for ISL could be contaminated from solution spills.
- The **Devladovo** site in **Ukraine** was leached with sulfuric and nitric acid. The surface of the site was heavily contaminated from spills of leaching solutions. Groundwater contamination is spreading downstream from the site at a speed of 53 m/year. It has traveled a distance of 1.7 km already and will reach the village of Devladovo after 24.5 years.

Production of fissile materials

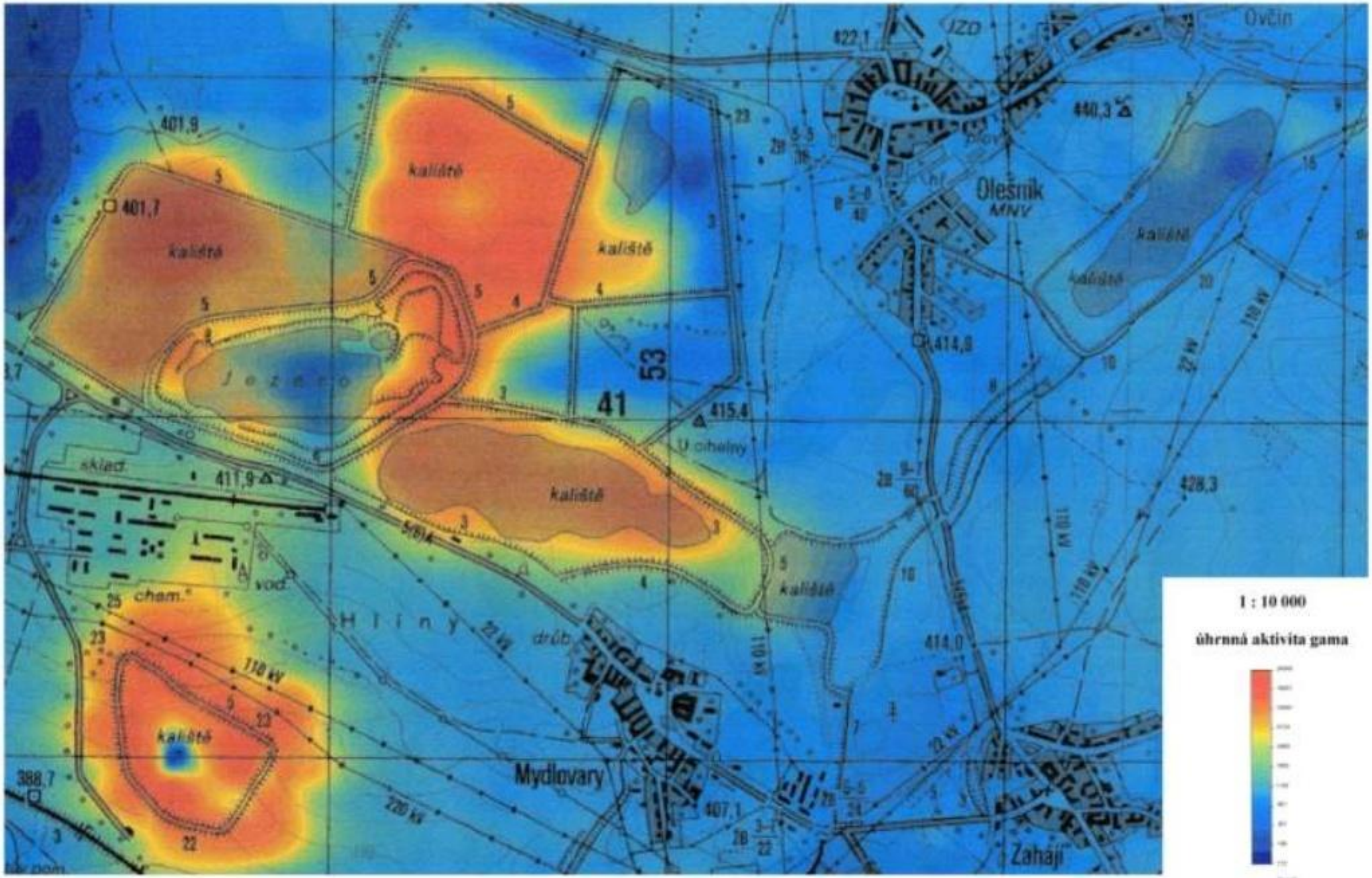
Chemical processing of mined ore (Mydlovary MAPE, 20 km from ETE):

- leaching with sodium bicarbonate (higher content of carbonates) or sulfuric acid (reduced content of carbonates)
- ratio of sulfuric acid up to 560 g of 94% acid per one liter of the leached material
- processed 16.7 mil. tonnes of ore, formation of tailing ponds with a total area of 300 ha - 36 mil. tonnes of sludge
- heavy metals and radioactive substances

Production of fissile materials

Radiokontaminace půd a sedimentů:

Uran, alfa zářiče, radon apod.



Production of fissile materials

Underground mine in Straz pod Ralskem

- 1966-1970 first attempts introducing methods of chemical leaching
- until the early 90s leaching fields with a total area of 7 km2
- during the entire period of the chemical extraction of underground injected more than 4 mil. tons of sulfuric acid

Production of fissile materials

Underground mine in Straz pod Ralskem

- contamination has spread to an area covering about 27 km2
- affected 370 mil. m3 of groundwater
- currently the contamination in an amount of 4.9 mil. t of solutes
- beginning of restoration

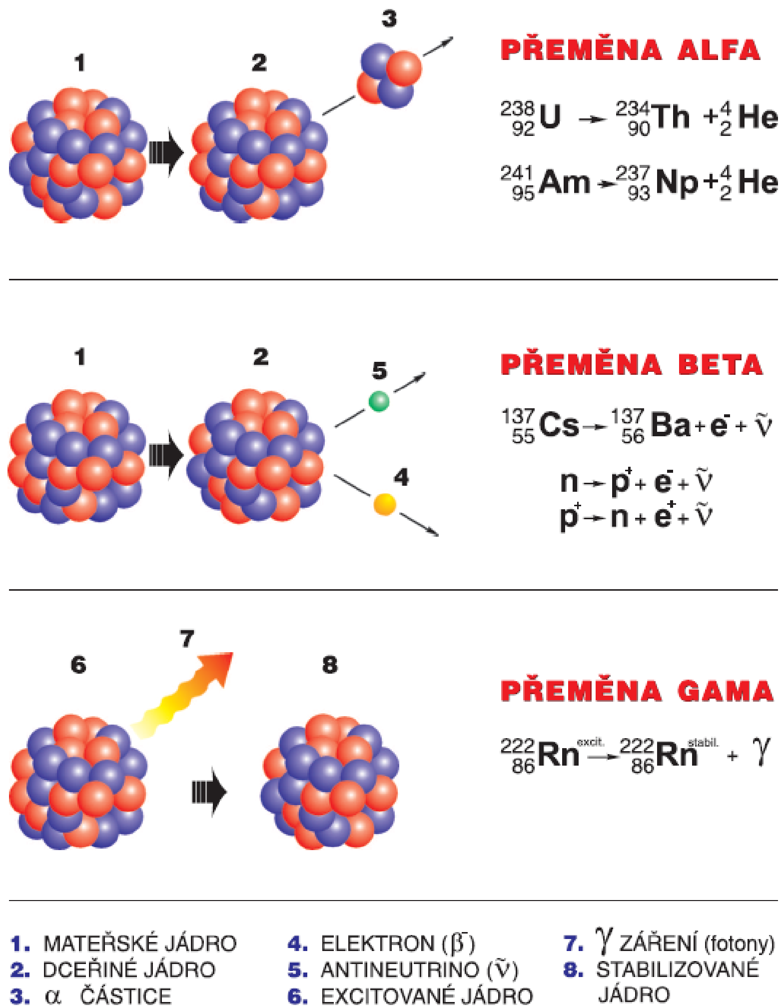
Restoration – Stráž pod Ralskem (DIAMO)

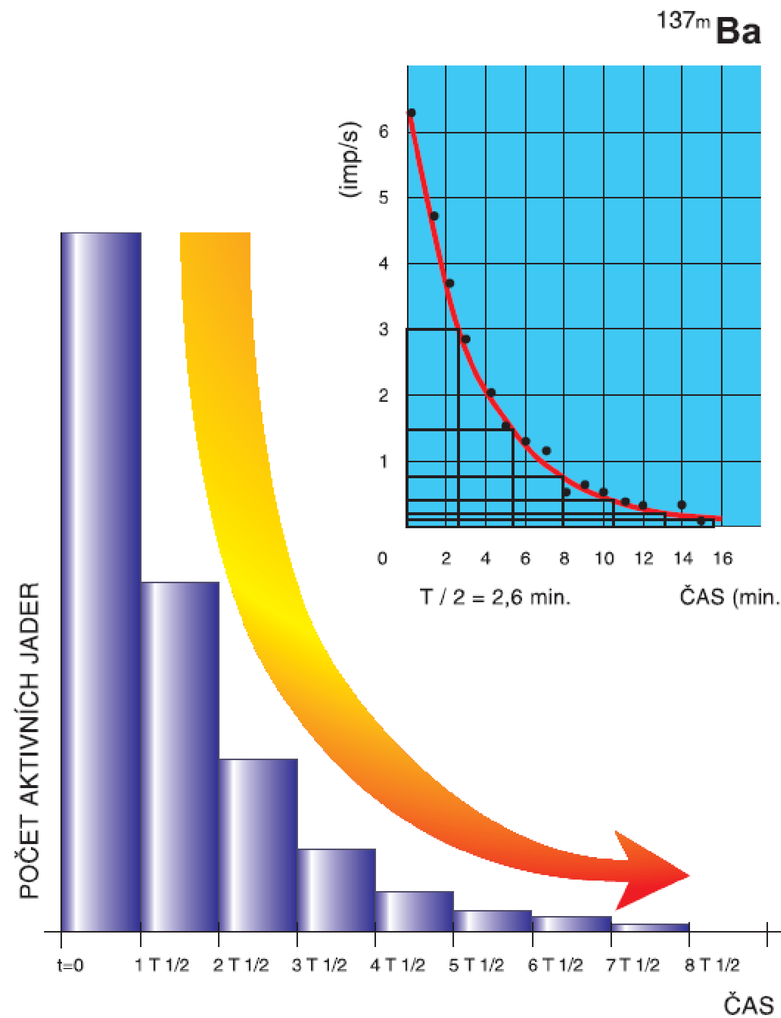
- restate geological environment to the state that will ensure exploitation of drinking water in the region
- dispose of wells and surface facilities
- incorporate the surface of extracted fields in ecosystems with regard to regional systems of ecological stability
- several stages of redevelopment, estimated cost of 40 billion CZK

Radioactivity

- radioactivity (or radioactive decay) is the spontaneous transformation of nuclei unstable nuclides other cores
- at the same time it generates ionizing radiation
- natural or artificial radioactivity
- transmutation
- decay of nuclei by decay series and the established principles

Radioactivity

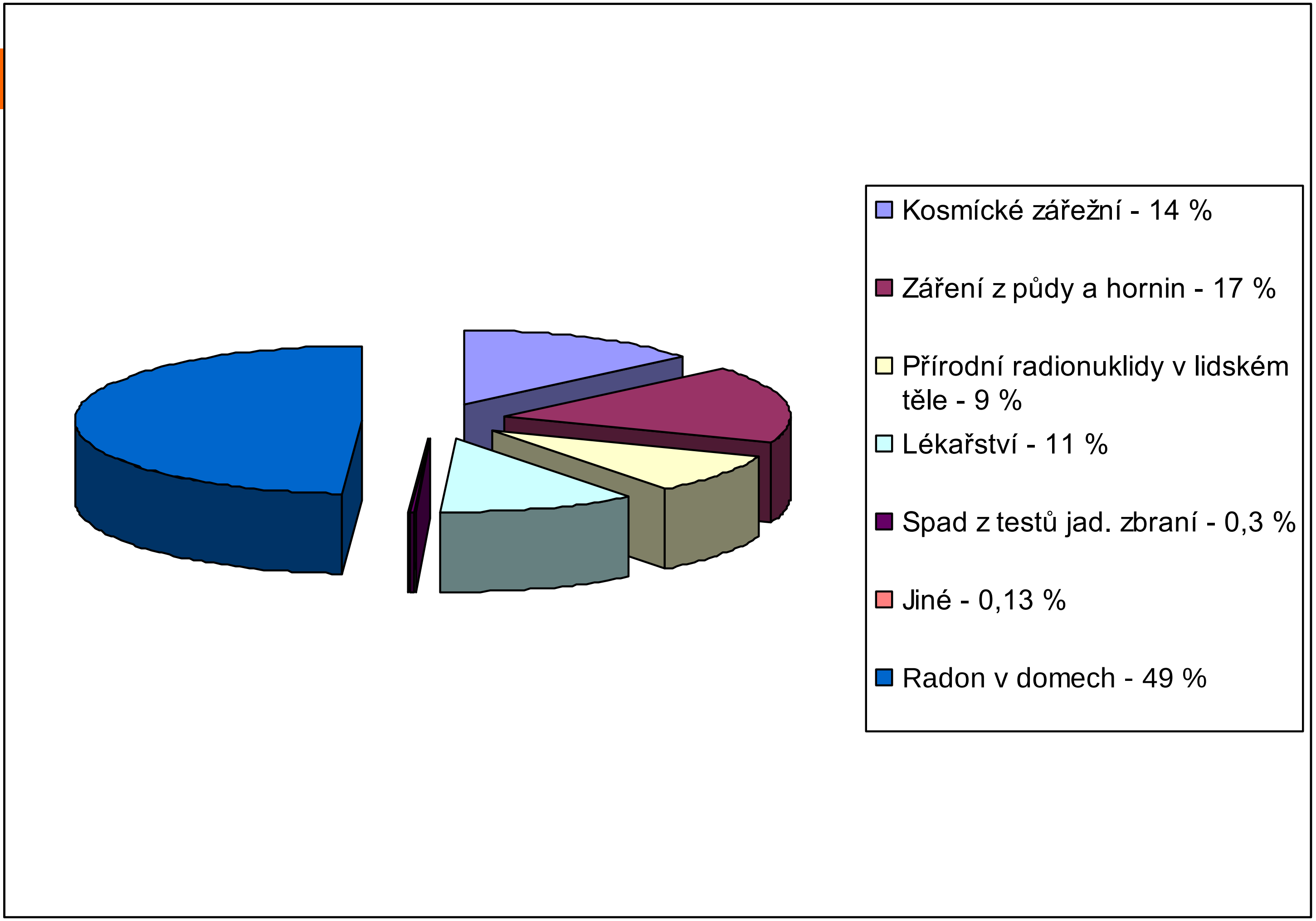




Radioactivity

- **cosmogenic radionuclides**: tritium ^{3}H (half-life 12,5 years), carbon ^{14}C (half-life 5730 years)
- **Primary radionuclides** : potassium ^{40}K (half-life $1,26x10^{9}$ years), thorium ^{232}Th (half-life $1,4x10^{10}$ years), uranium ^{238}U (half-life $4,5x10^{9}$ years), ^{235}U ($7x10^{8}$ years)
- **Secondary radionuclides**: radionuclides of decay series – thorium, uranium, aktinouranium, neptunim

Sources of radiation



Cosmic 14%

Ground 17%

Natural radionuclides in human body 9%

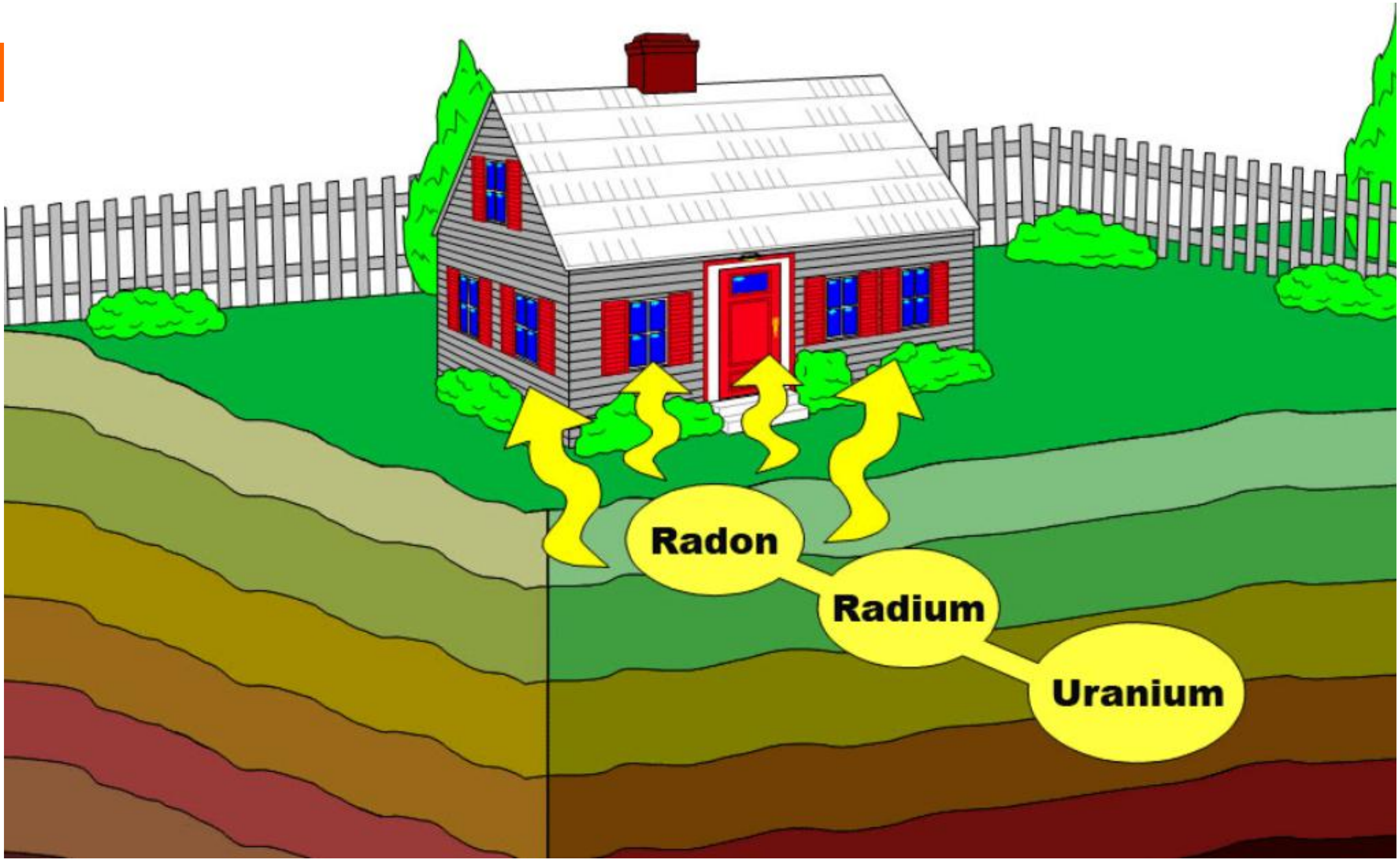
Medicine 11%

Nuclear fallout 0,3%

Other 0,13 %

Radon in houses 49%

Radon



Nuclear energy safety and environmental aspects

- the use of nuclear energy is regulated by law
- Nuclear safety is not a mere formality, it is an enforceable requirement
- All effects are monitored and evaluated
- responsibility is transferred to the operator's license holder

Nuclear safety – deep protection

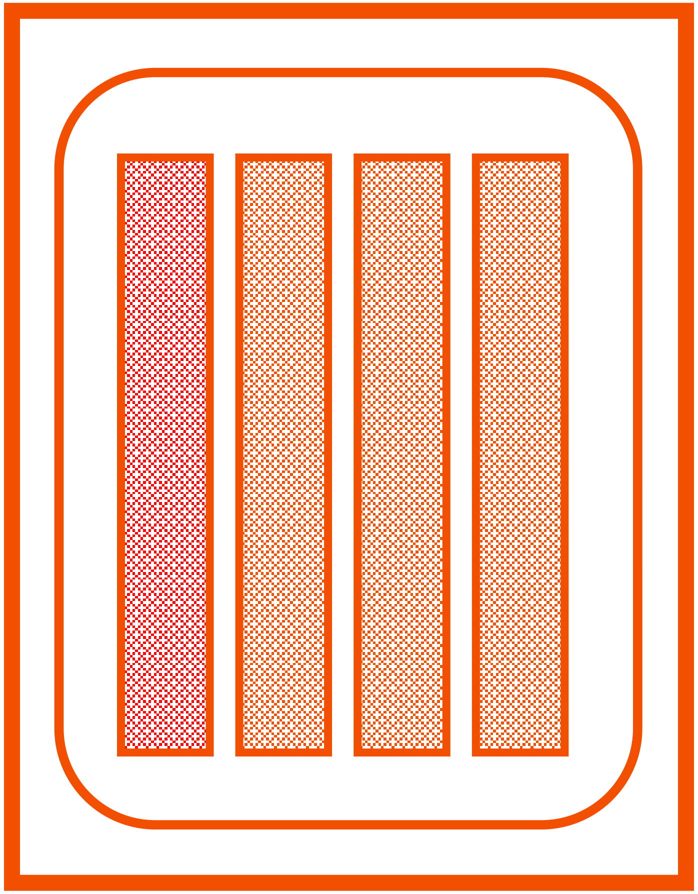
Deep protection = means to achieve the basic objective of safety

First barrier: **molecular matrix fuel** (almost all the fission products resulting from fission are captured in the matrix of the uranium tablets)

Second barrier: **hermetic fuel cladding** (an alloy of zirconium-niobium)

Third barrier: **the primary circuit pressure limit** (resistant to high pressure, temperature, radiation and radiation dynamic conditions of operation)

Fourth barrier: **hermetic borders of rooms - containment** (building design protection, resists airplane crash, blast wave, explosion, storm, extreme temperatures, extreme precipitation, etc.)



Operation of nuclear power plant

- nuclear fission
- necessary operating conditions
- waste production
- disposal of spent nuclear fuel

All the above can be part of the process or source of ionizing radiation.

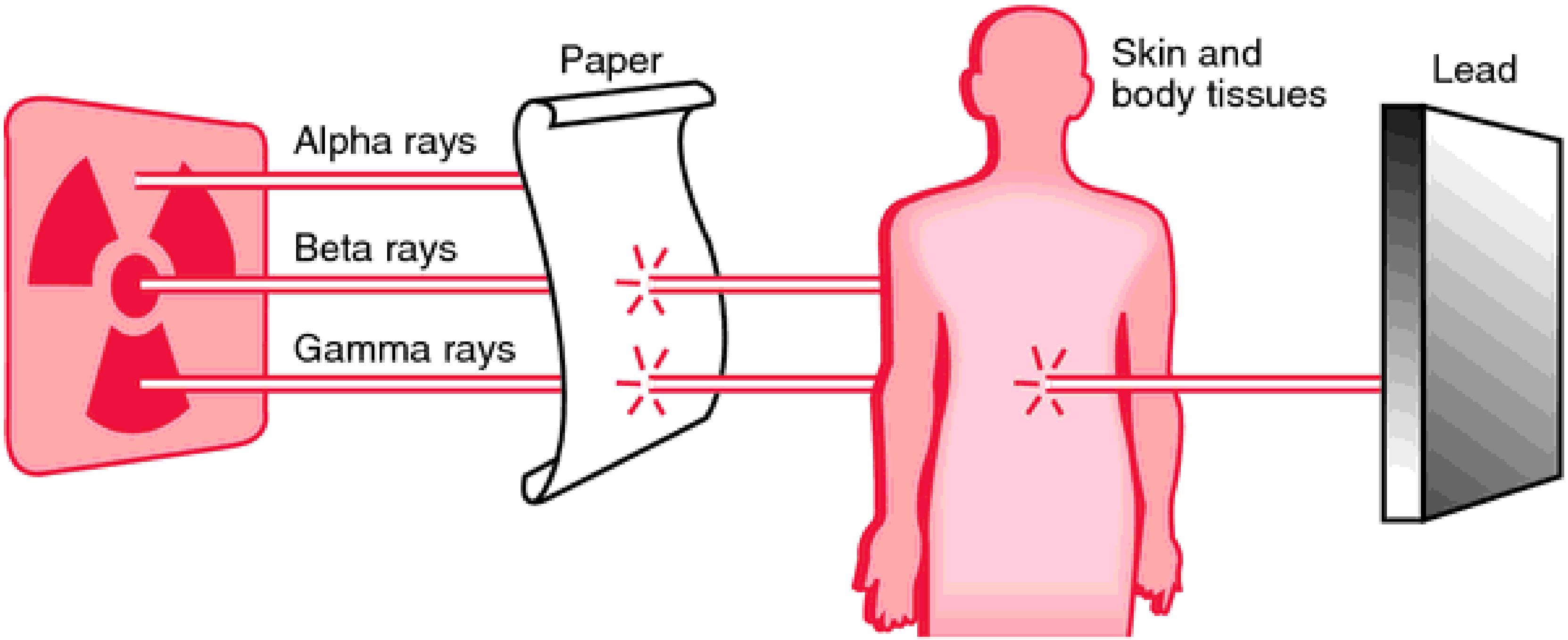
Protection against radiation

Distance - ionizing radiation intensity decreases with the square of the distance, ie. after 10 m it is 100 times lower, after 100 m it is 10000 times lower, after 1 km it is a million times lower.

Time - the shorter the exposure, the smaller the cumulative dose

Shielding - depending on the type of radiation: alpha radiation skin tones, clothing, paper; beta radiation, aluminum sheet; gamma rays concrete, a layer of water, soil; neutron radiation, water, polystyrene, paraffin.

Protection against radiation



Protection against radiation

Objective of the radiation protection

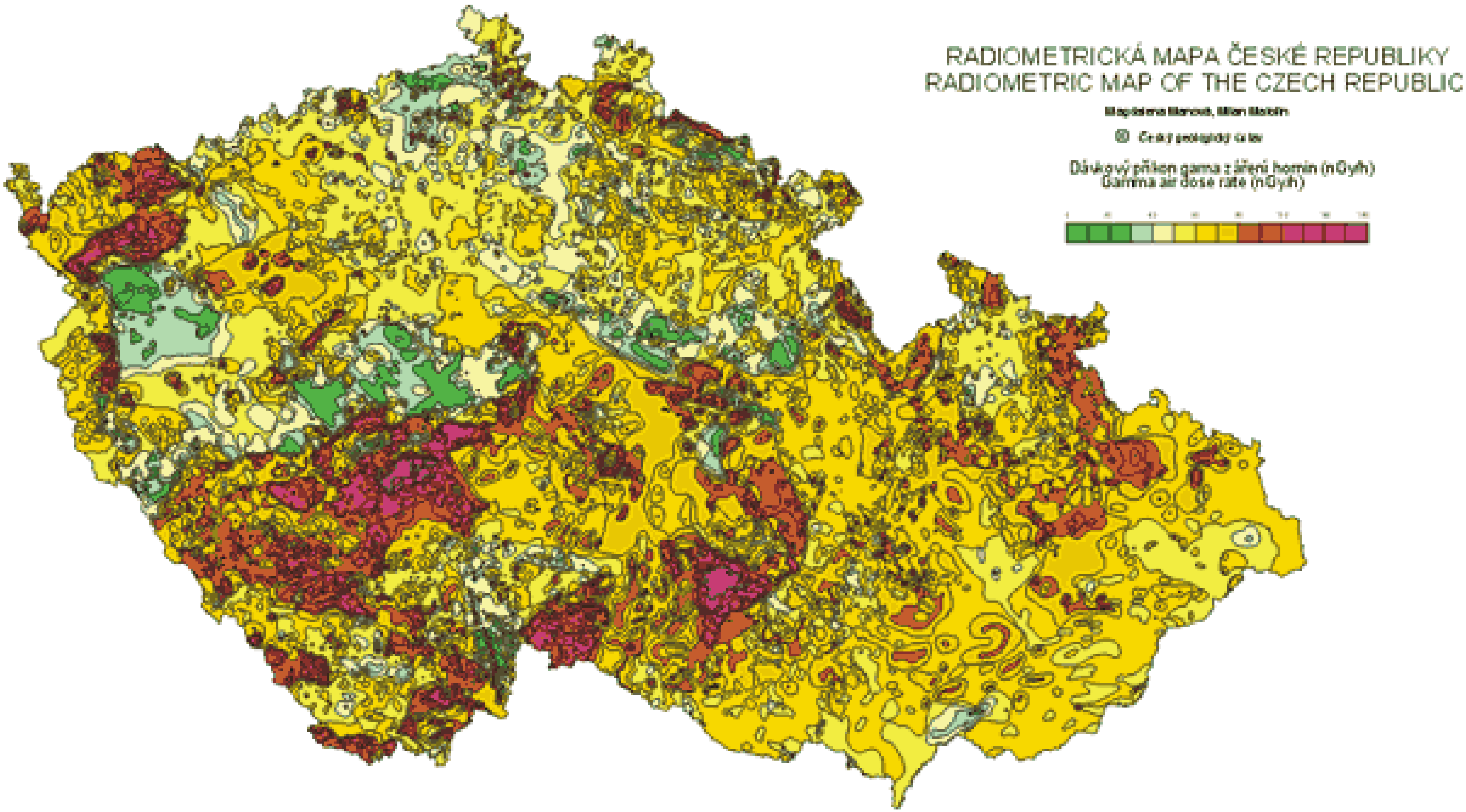
To ensure that during normal operation the radiation exposure inside the device and/or the release of radioactive materials into the environment is as low as reasonably achievable, taking into consideration economic and social factors and prescribed limits and ensure mitigate the extent of exposure to radiation accidents.

The principle of ALARA

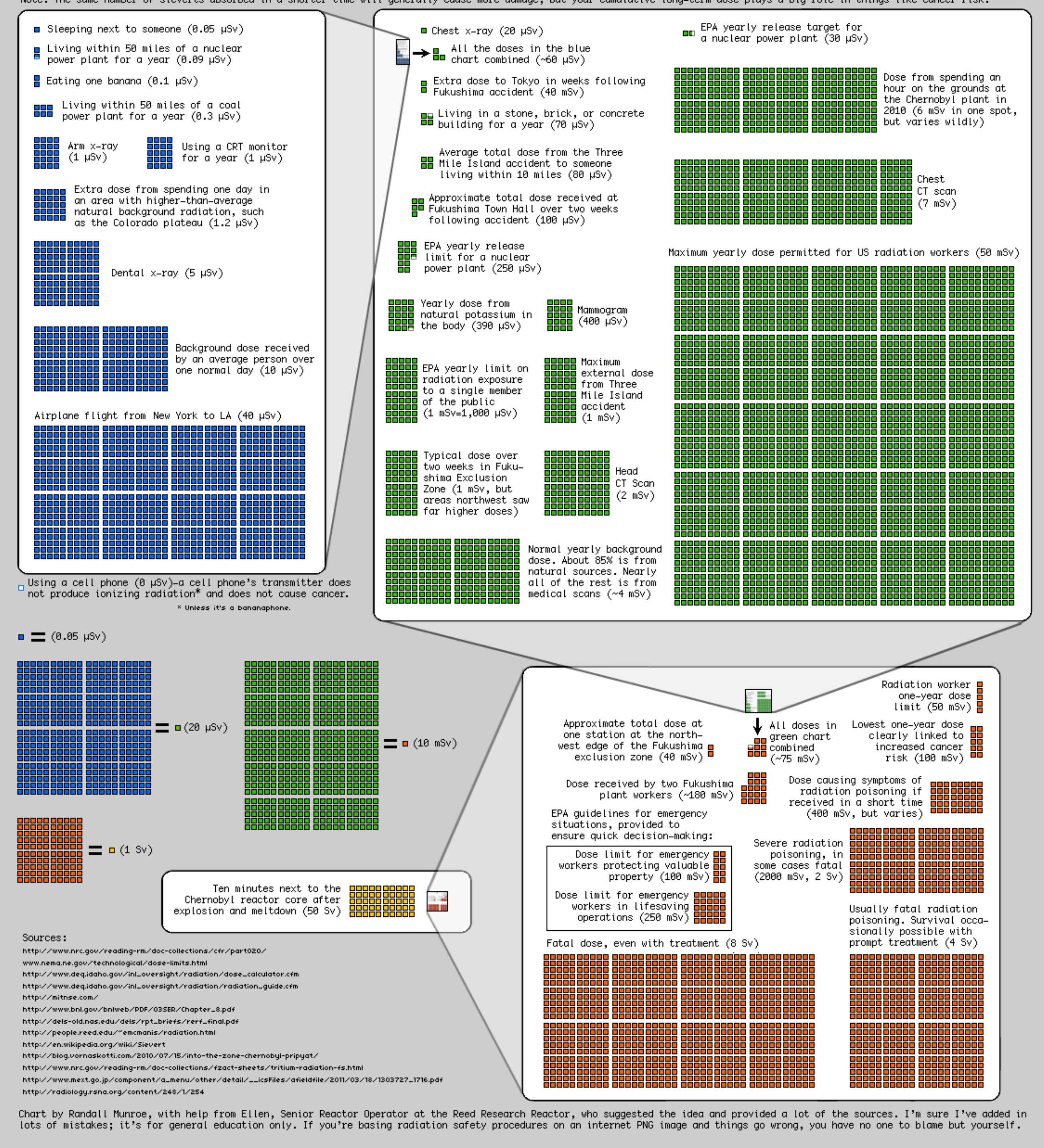
Observe the rules and seek new and better ways of performing work

Already applied in the design

Czech Republic	-	cca 3 mSv/year
Iran (Ramsar)	-	up to 400 mSv/year
India (Kerala)	-	up to 17 mSv/year
Brazil (Guarapari)	-	up to 175 mSv/year



Protection



Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose plays a big role in things like cancer risk.
Sleeping next to someone (0.05 μSv)
Living within 50 miles of a nuclear power plant for a year (0.09 μSv)
Eating one banana (0.1 μSv)
Living within 50 miles of a coal power plant for a year (0.3 μSv)
Arm x-ray (1 μSv)
Using a CRT monitor for a year (1 μSv)
Extra dose from spending one day in an area with higher-than-average natural background radiation, such as the Colorado plateau (1.2 μSv)
Dental x-ray (5 μSv)
Background dose received by an average person over one normal day (10 μSv)
Airplane flight from New York to LA (40 μSv)
Using a cell phone (0 μSv)—a cell phone's transmitter does not produce ionizing radiation* and does not cause cancer.
* Unless it's a bananaphone.
Chest x-ray (20 μSv)
All the doses in the blue chart combined (~60 μSv)
Extra dose to Tokyo in weeks following Fukushima accident (40 μSv)
Living in a stone, brick, or concrete building for a year (70 μSv)
Average total dose from the Three Mile Island accident to someone living within 10 miles (80 μSv)
Approximate total dose received at Fukushima Town Hall over two weeks following accident (100 μSv)
EPA yearly release limit for a nuclear power plant (250 μSv)
Yearly dose from natural potassium in the body (390 μSv)
Mammogram (400 μSv)
EPA yearly limit on radiation exposure to a single member of the public (1 mSv=1,000 μSv)
Maximum external dose from Three Mile Island accident (1 mSv)
Typical dose over two weeks in Fukushima Exclusion Zone (1 mSv, but areas northwest saw far higher doses)
Head CT Scan (2 mSv)
Normal yearly background dose. About 85% is from natural sources. Nearly all of the rest is from medical scans (~4 mSv)
EPA yearly release target for a nuclear power plant (30 μSv)
Dose from spending an hour on the grounds at the Chernobyl plant in 2010 (6 mSv in one spot, but varies wildly)
Chest CT scan (7 mSv)
Maximum yearly dose permitted for US radiation workers (50 mSv)
= (0.05 μSv)
= (20 μSv)
= (10 mSv)
= (1 Sv)
Ten minutes next to the Chernobyl reactor core after explosion and meltdown (50 Sv)
Radiation worker one-year dose limit (50 mSv)
Approximate total dose at one station at the northwest edge of the Fukushima exclusion zone (40 mSv)
All doses in green chart combined (~75 mSv)
Lowest one-year dose clearly linked to increased cancer risk (100 mSv)
Dose received by two Fukushima plant workers (~180 mSv)
Dose causing symptoms of radiation poisoning if received in a short time (400 mSv, but varies)
EPA guidelines for emergency situations, provided to ensure quick decision-making:
Dose limit for emergency workers protecting valuable property (100 mSv)
Dose limit for emergency workers in lifesaving operations (250 mSv)
Severe radiation poisoning, in some cases fatal (2000 mSv, 2 Sv)
Usually fatal radiation poisoning. Survival occasionally possible with prompt treatment (4 Sv)
Fatal dose, even with treatment (8 Sv)
Sources:
http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/
www.nema.ne.gov/technological/dose-limits.html
http://www.deq.idaho.gov/inl_oversight/radiation/dose_calculator.cfm
http://www.deq.idaho.gov/inl_oversight/radiation/radiation_guide.cfm
http://mitnse.com/
http://www.bnl.gov/bnlweb/PDF/03SER/Chapter_8.pdf
http://dels-old.nas.edu/dels/rpt_briefs/rerf_final.pdf
http://people.reed.edu/~emcmanis/radiation.html
http://en.wikipedia.org/wiki/Sievert
http://blog.vornaskotti.com/2010/07/15/into-the-zone-chernobyl-pripyat/
http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/tritium-radiation-fs.html
http://www.mext.go.jp/component/a_menu/other/detail/__icsFiles/afieldfile/2011/03/18/1303727_1716.pdf
http://radiology.rsna.org/content/248/1/254
Chart by Randall Munroe, with help from Ellen, Senior Reactor Operator at the Reed Research Reactor, who suggested the idea and provided a lot of the sources. I'm sure I've added in lots of mistakes; it's for general education only. If you're basing radiation safety procedures on an internet PNG image and things go wrong, you have no one to blame but yourself.

Porovnání ra

Type of Radiation (dose in mSv)†	Equivalent Period of Natural Background Radiation‡	Estimated Lifetime Risk of dying from cancer that results from a single exposure§
Airport Security x-ray scanner [23] (~0.0001mSv)	less than one hour	Almost 0 (less than 1 in 100,000,000)
7 hour airplane flight [9] (~0.03 mSv)	a few days	Almost 0 (1 in 1,000,000 – 100,000)
Chest x-ray [6] (~0.1 mSv)	~ one week	Almost 0 (1 in 1,000,000 – 100,000)
Mammogram [27] (~0.4 mSv)	a few months (~2 months)	1 in 100,000 to 10,000
CT of chest [27] (~7mSv)	a few years (~2.3 years)	1 in 10,000 to 1,000
Fluoroscopy: colon (barium enema) [27] (~8mSv)	a few years (~2.7 years)	1 in 10,000 to 1,000
CT of heart (angiography) [27] (~16 mSv)	a few years (~5.3 years)	1 in 10,000 to 1,000
PET scan, whole body [5] (~14 mSv)	a few years (~4.6 years)	1 in 10,000 to 1,000
Fluoroscopy: kidneys, ureters and bladder [5] (~15mSv)	a few years (~5 years)	1 in 10,000 to 1,000
Whole-body CT scan [5] (~22.5 mSv)	several years (~7.5 years)	1 in 1,000
Nuclear Medicine: Cardiac stress-rest test (thallium) [27] (~40.7mSv)	many years (~13.6 years)	~2 in 1,000
Transjugular intrahepatic portosystemic shunt placement [27] (~70mSv)	many years (~23.3 years)	1 in 100 – 1,000
Lifetime risk of cancer death NOT caused by radiation§§		1 in 5

Radiation Dose to Patients From Common Imaging Examinations

Region	Procedure	**Approximate effective radiation dose	Comparable to natural background radiation for	* Estimated lifetime risk of fatal cancer from examination
ABDOMINAL REGION	Computed Tomography (CT) — Abdomen and Pelvis	10 mSv	3 years	Low
	Computed Tomography (CT) — Abdomen and Pelvis, repeated with and without contrast material	20 mSv	7 years	Moderate
	Computed Tomography (CT) — Colonography	10 mSv	3 years	Low
	Intravenous Pyelogram (IVP)	3 mSv	1 year	Low
	Radiography (X-ray) — Lower GI Tract	8 mSv	3 years	Low
	Radiography (X-ray) — Upper GI Tract	6 mSv	2 years	Low
BONE	Radiography (X-ray) — Spine	1.5 mSv	6 months	Very Low
	Radiography (X-ray) — Extremity	0.001 mSv	3 hours	Negligible
CENTRAL NERVOUS SYSTEM	Computed Tomography (CT) — Head	2 mSv	8 months	Very Low
	Computed Tomography (CT) — Head, repeated with and without contrast material	4 mSv	16 months	Low
	Computed Tomography (CT) — Spine	6 mSv	2 years	Low
CHEST	Computed Tomography (CT) — Chest	7 mSv	2 years	Low
	Computed Tomography (CT) — Lung Cancer Screening	1.5 mSv	6 months	Very Low
	Radiography — Chest	0.1 mSv	10 days	Minimal
DENTAL	Intraoral X-ray	0.005 mSv	1 day	Negligible
HEART	Coronary Computed Tomography Angiography (CTA)	12 mSv	4 years	Low
	Cardiac CT for Calcium Scoring	3 mSv	1 year	Low
MEN'S IMAGING	Bone Densitometry (DEXA)	0.001 mSv	3 hours	Negligible
NUCLEAR MEDICINE	Positron Emission Tomography — Computed Tomography (PET/CT)	25 mSv	8 years	Moderate
WOMEN'S IMAGING	Bone Densitometry (DEXA)	0.001 mSv	3 hours	Negligible
	Mammography	0.4 mSv	7 weeks	Very Low

*Risk Level	Negligible	Minimal	Very Low	Low	Moderate
Estimated additional risk of fatal cancer for an adult from examination	Less than 1 in 1,000,000	1 in 1,000,000 to 1 in 100,000	1 in 100,000 to 1 in 10,000	1 in 10,000 to 1 in 1,000	1 in 1,000 to 1 in 500

Note: These risk levels represent very small additions to the 1 in 5 chance we all have of dying from cancer.

Important: Pediatric patients vary in size. Doses given to pediatric patients will vary significantly from those given to adults.

RadiologyInfo.org *The radiology information resource for patients*

RSNA Radiological Society of North America

ACR American College of Radiology Quality is our image

RADIATION DOSAGE CHART

This office is dedicated to providing our patients with the safest, most comfortable experience possible. Good quality diagnostic x-rays are crucial to maintaining your overall health. Be assured we are doing everything possible to keep you healthy by following the ALARA* principle. Please do not hesitate to ask questions or discuss your concerns.

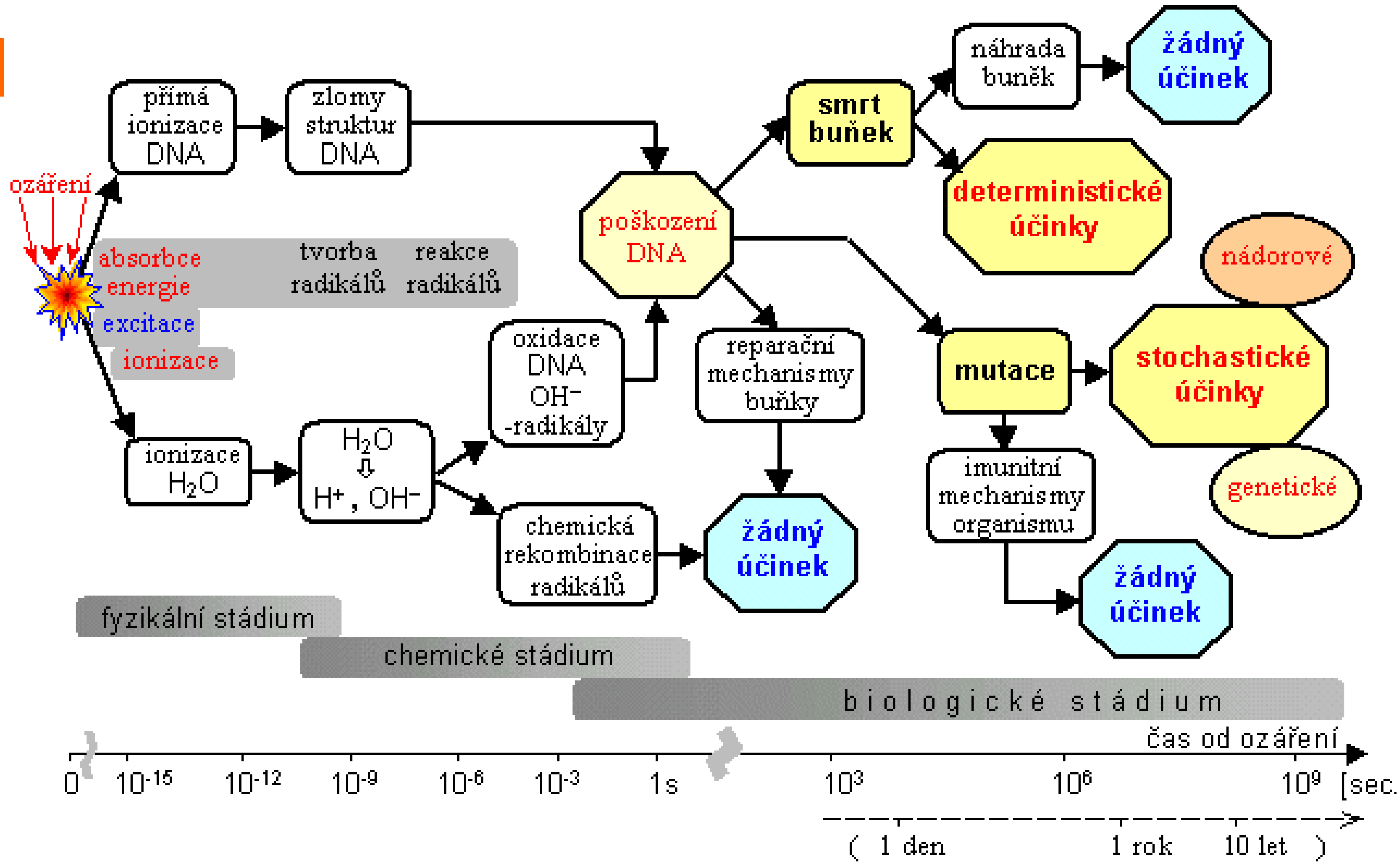
.00005	Sleeping next to someone
.00009	Living within 50 miles of a nuclear power plant for a year
.00010	Eating a banana
.00025	Airport security scan
.001	Using a CRT monitor for one year
.005	Dental X-ray
.01	Background dose received by average person on an average day
.04	Flight from New York to LA
.07	Living in a stone, brick or concrete building for one year
.1	Chest X-ray
.4	Annual dose received through food
1.5	Spinal X-ray
2.4	Average background dose per person per year (natural background radiation)
4.0	Mammogram
6.0	Dose from spending one hour on the ground at Chernobyl (2010)
10.0	Average CT scan
36.0	Smoking 1.5 packs a day for one year
50.0	Maximum annual dose permitted in US radiation workers

RADIATION DOSES Millisieverts (mSv)

10,000	Acute radiation poisoning – death within weeks
6,000	Typical dose received by Chernobyl nuclear plant workers who died within one month of accident
3,000	Survival rate approximately 50 percent
2,200	Reading found near tanks used to store radioactive water at Fukushima plant, Sep 3, 2013
1,000	Causes radiation sickness and nausea, but not death. Likely to cause fatal cancer many years later in about 5 of every 100 persons exposed
700	Vomiting, hair loss within 2-3 weeks
500	Allowable short-term dose for emergency workers taking life-saving actions
400 per hour	Peak radiation level recorded inside Fukushima plant four days after accident
350 per lifetime	Exposure level used as criterion for relocating residents after Chernobyl accident
250	Allowable short-term dose for workers controlling 2011 Fukushima accident
100	Lowest level linked to increased cancer risk
20 per year	Average limit for nuclear industry workers
10	Full-body CT scan
2.4 per year	Person's typical exposure to background radiation
0.01	Dental x-ray

Long distance flights in 10 km altitude = ca. 4 μSv/hod

Chemical effects of radiation



Effects on human organism

Stochastic (random) - few cells damaged, subliminal dose or repeated small doses.

- we can only calculate the probability of injury, no injury may in fact occur.
- can be detected only by observing a large number of people. Risk of small doses? Scientists still do not match, they can not confirm nor deny it for there is not a sample of people who are not exposed to any radiation at all. No control sample.
- It is known that there is a "protective effect" radiation (hormesis) - in places with higher radioactivity there is less incidence of cancer (cells repair any damage).

Effects on human organism

Non-stochastic effects (deterministic) - after a large dose of radiation, many cells, appear in a short time.

Examples:

local dermatitis
Lenticular opacities
birth defects
fertility
Acute radiation sickness

Protection against outer sources

Protection against earthquake

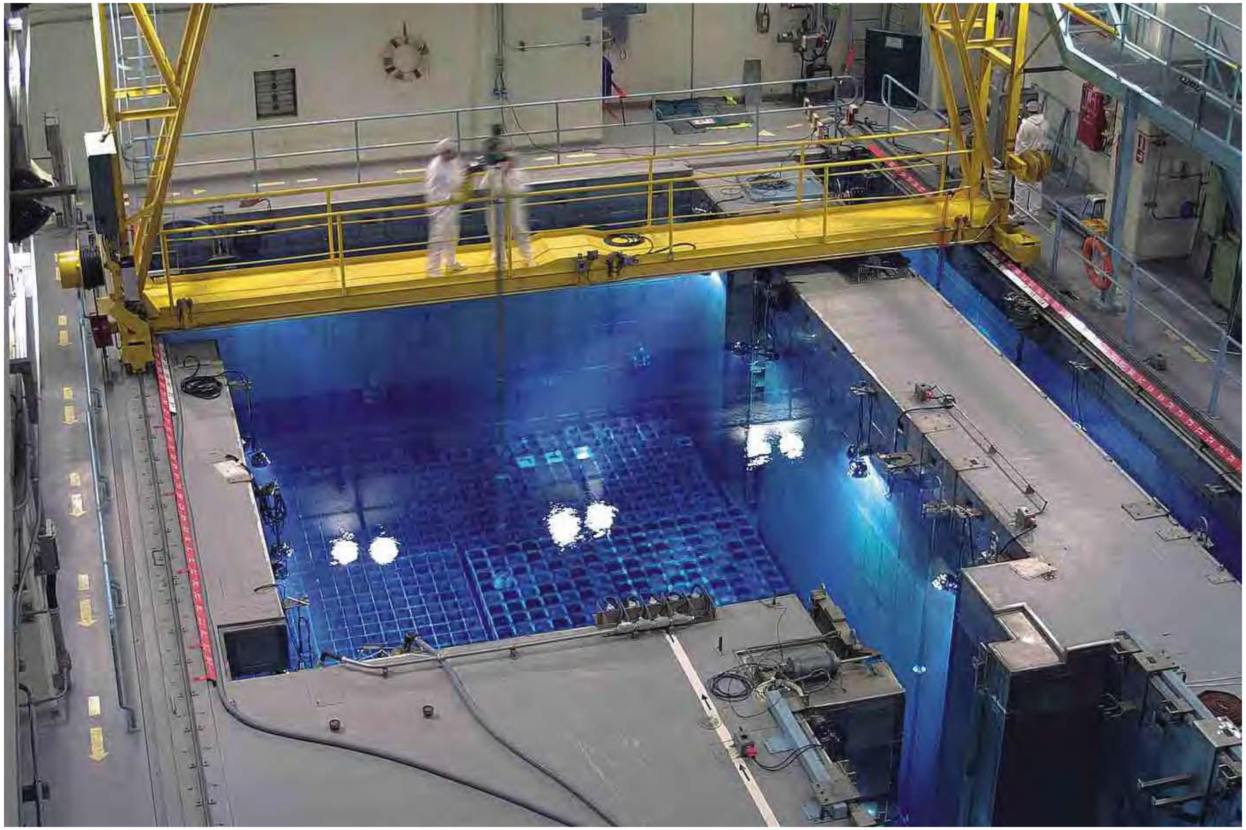
Protection from flood and adverse meteorological phenomena

Protection against pressure waves from explosions

Protection against the effects caused by the fall of the aircraft

Protection against the influence of third parties

Storage



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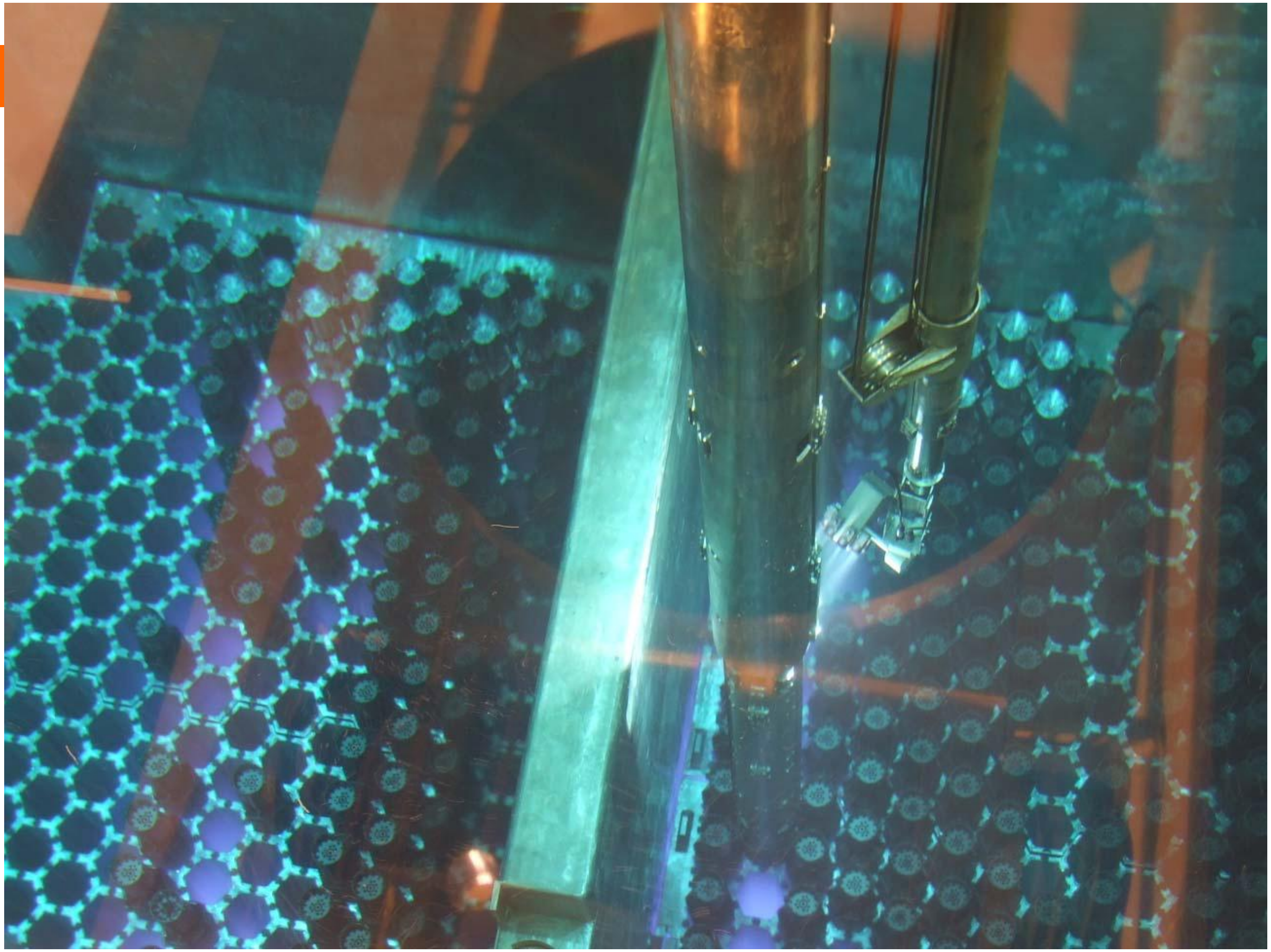


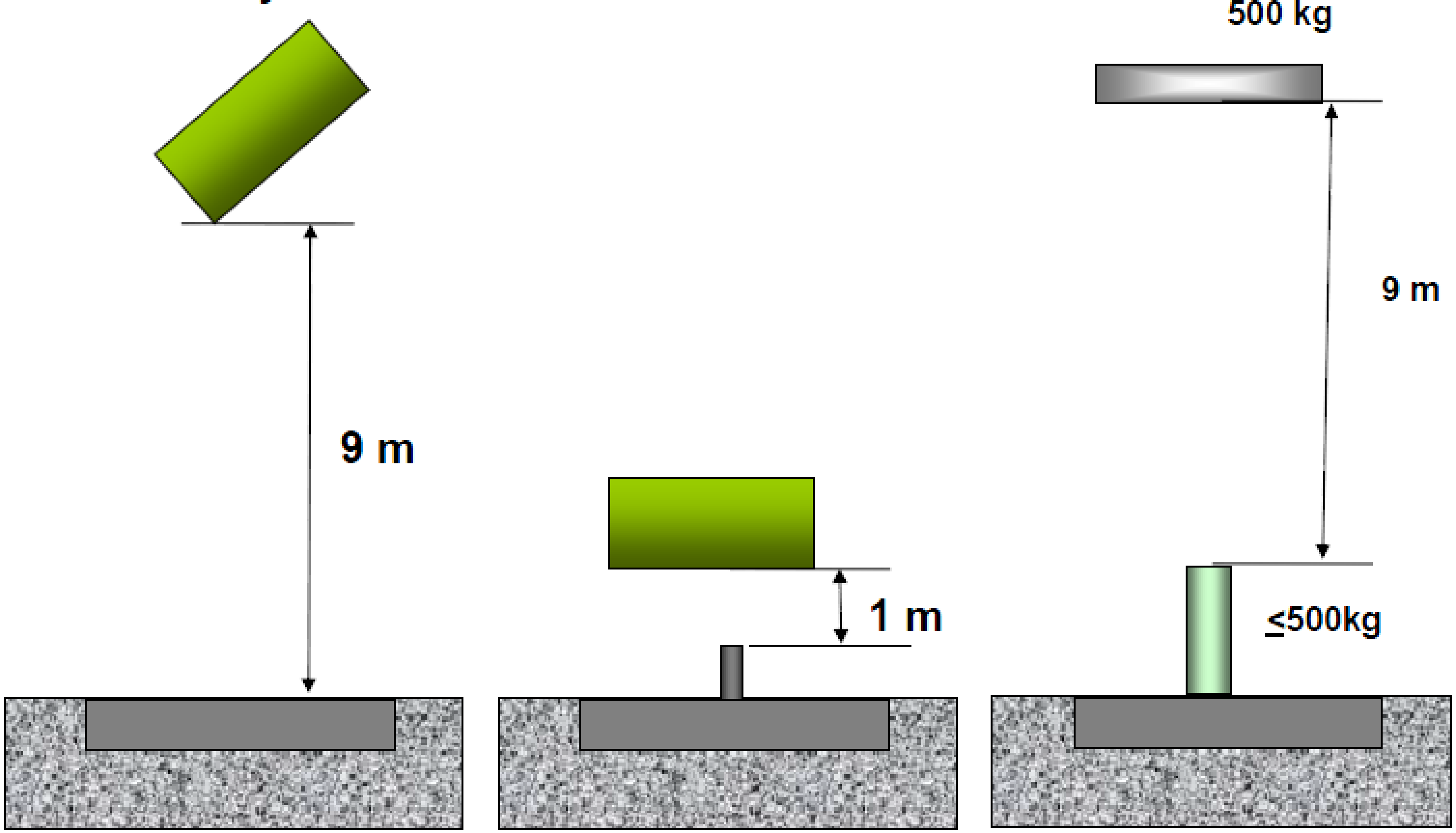
Storage

Storage

Storage

Zkoušky prokazující schopnost přestát podmínky nehody při přepravě

- **Pádové zkoušky**



Storage

Zkoušky prokazující schopnost přestát podmínky nehody při přepravě

- Požár
- Ponoření