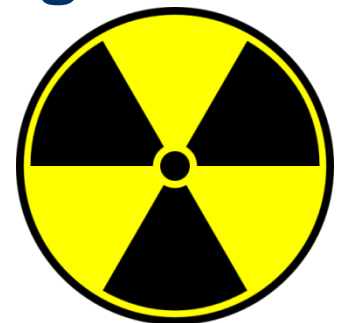


# **Environmental aspects of nuclear energy**

**PhDr. Tomáš Vlček, Ph.D.  
(Ing. Jiří Martinec, Ph.D.)**

# 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

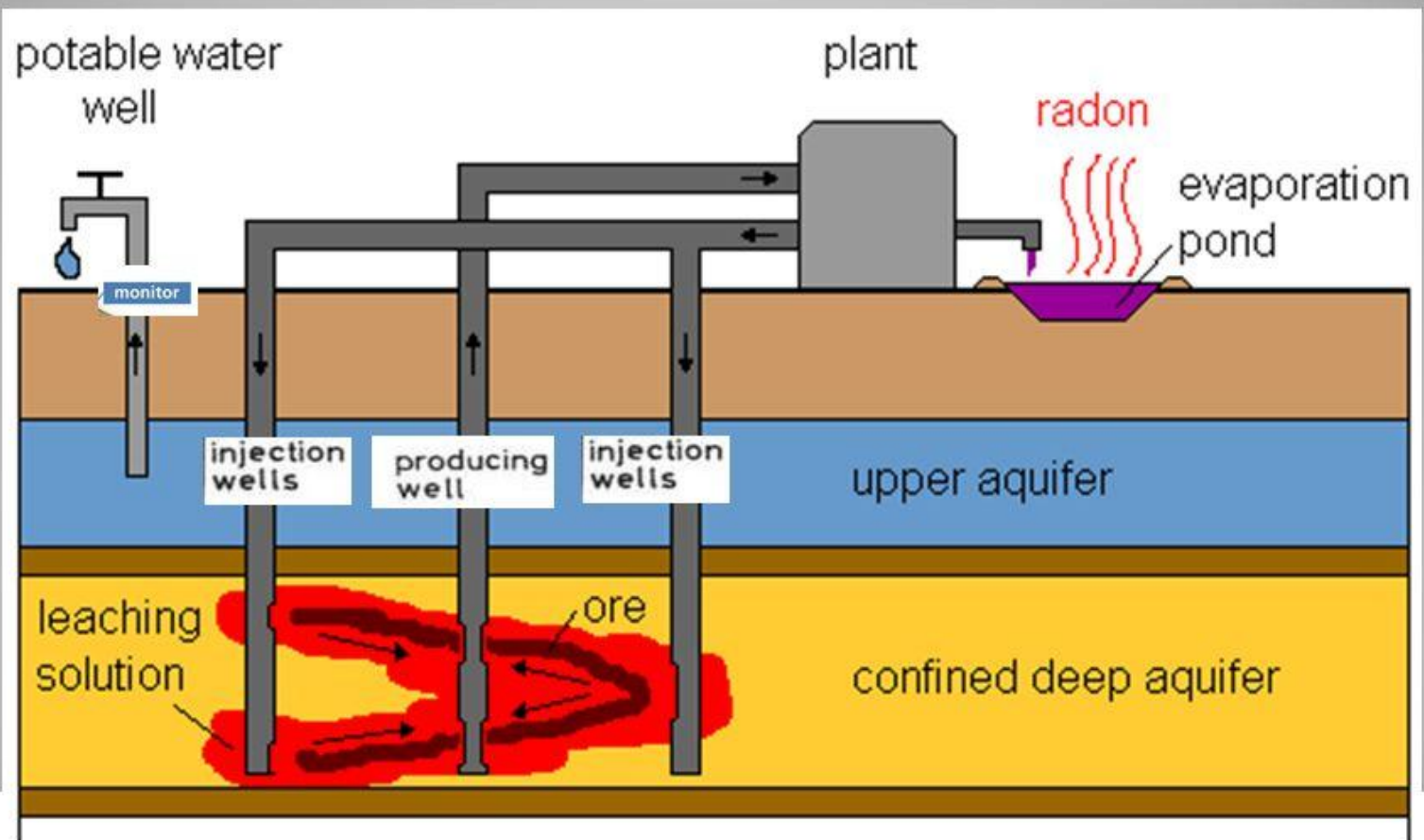


# In Situ Leaching

- **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.



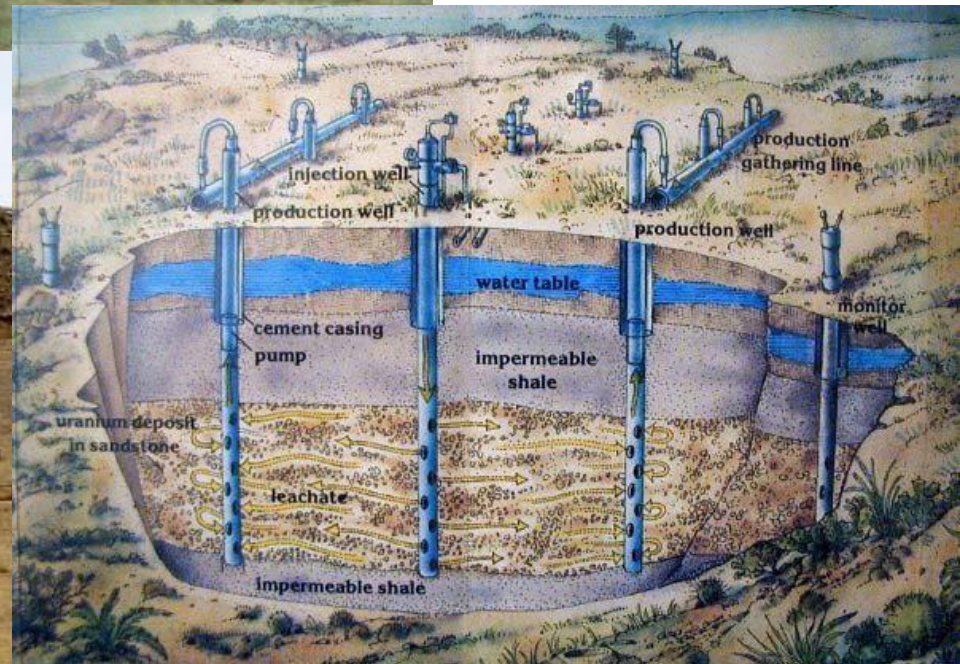
# In Situ Leaching











# 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<sup>3</sup> 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<sup>3</sup> of contaminated liquid is contained in the leaching zone, covering an area of 5.74 km<sup>2</sup>. 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<sup>2</sup> and a further 235 million m<sup>3</sup> 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

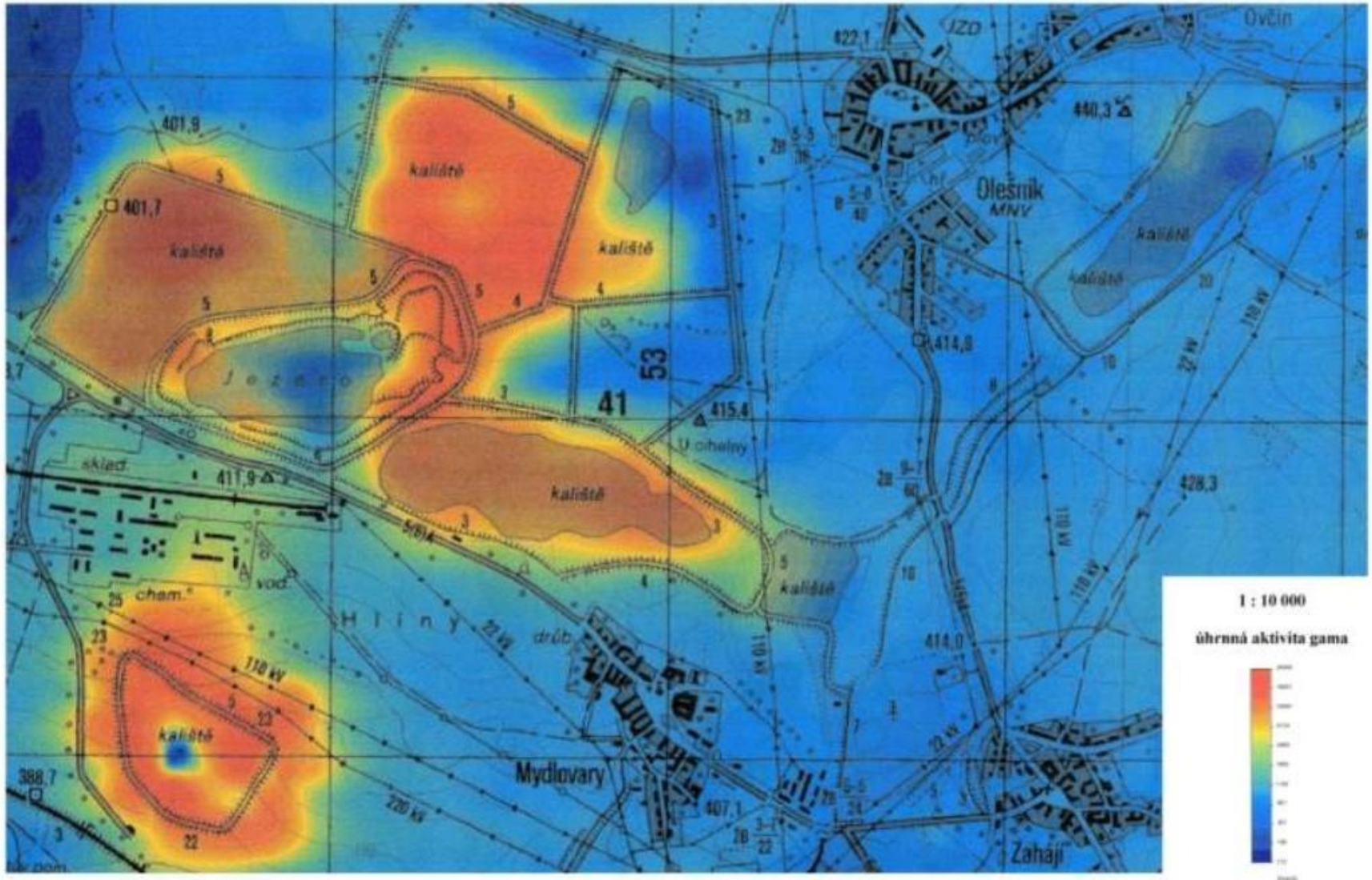
# Production of fissile materials





# 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 km<sup>2</sup>
- 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 km<sup>2</sup>
- affected 370 mil. m<sup>3</sup> of groundwater
- currently the contamination in an amount of 4.9 mil. t of solutes
- beginning of restoration

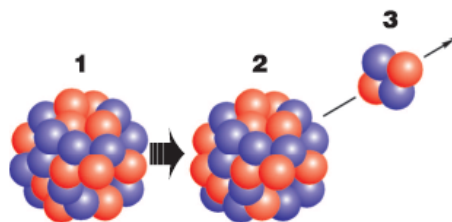
## Restoration – Stráž pod Ralskem (DIAMO)

- 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

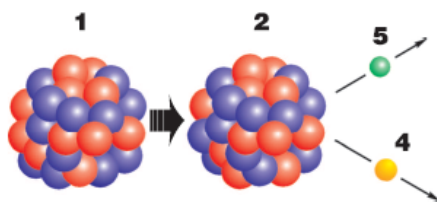
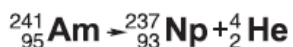
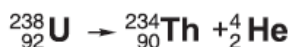
# Radioactivity

- 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

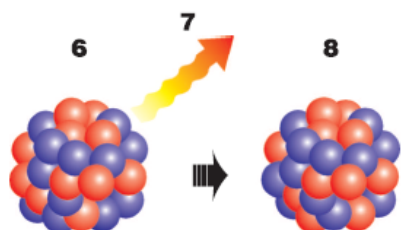
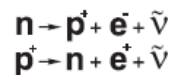
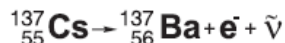
# Radioactivity



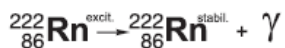
## PŘEMĚNA ALFA



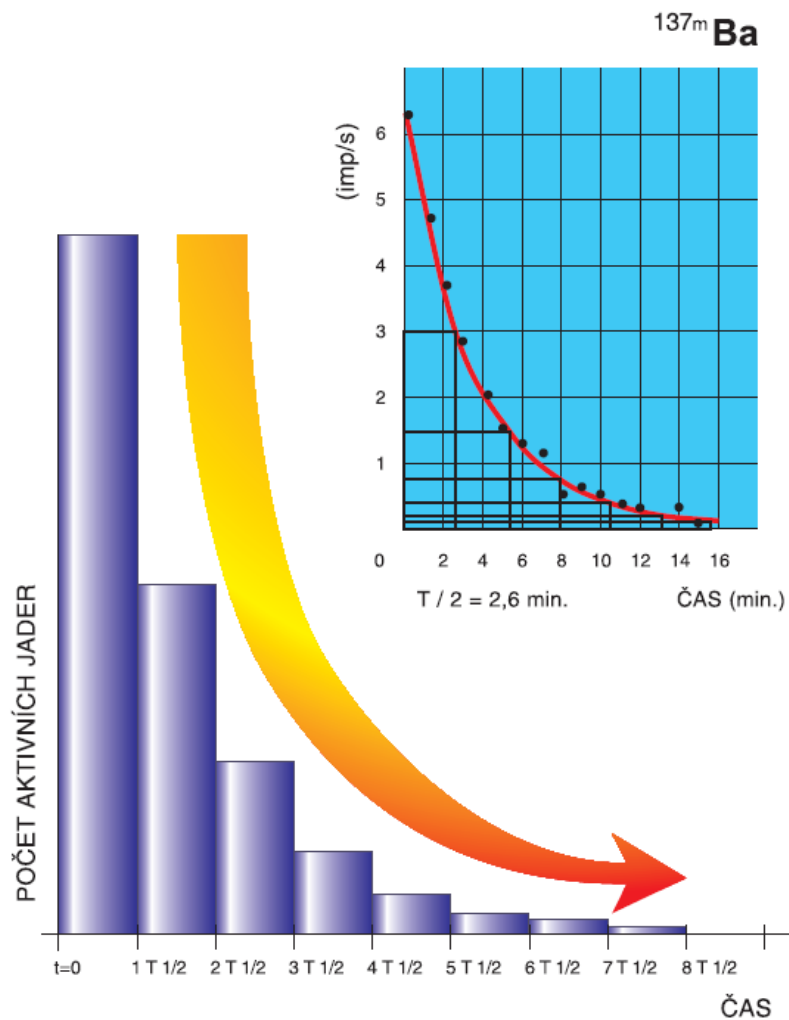
## PŘEMĚNA BETA



## PŘEMĚNA GAMA



- |                     |                                 |                             |
|---------------------|---------------------------------|-----------------------------|
| 1. MATEŘSKÉ JÁDRO   | 4. ELEKTRON ( $\beta^-$ )       | 7. $\gamma$ ZÁŘENÍ (fotony) |
| 2. DCEŘINÉ JÁDRO    | 5. ANTINEUTRINO ( $\bar{\nu}$ ) | 8. STABILIZOVANÉ JÁDRO      |
| 3. $\alpha$ ČÁSTICE | 6. EXCITOVANÉ JÁDRO             |                             |

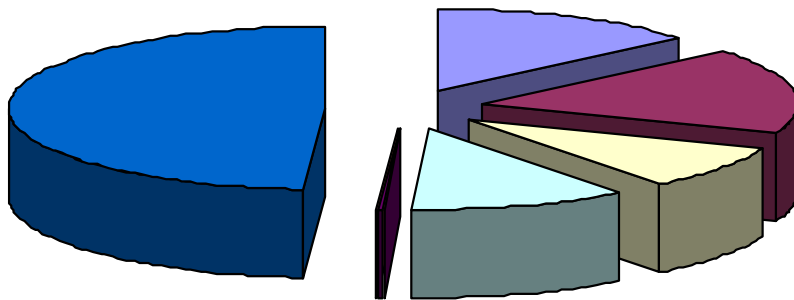




# Radioactivity

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

# Sources of radiation



- Kosmické zářeží - 14 %
- Záření z půdy a hornin - 17 %
- Přírodní radionuklidy v lidském těle - 9 %
- Lékařství - 11 %
- Spad z testů jad. zbraní - 0,3 %
- Jiné - 0,13 %
- Radon v domech - 49 %

Cosmic 14%

Ground 17%

Natural radionuclides in human body 9%

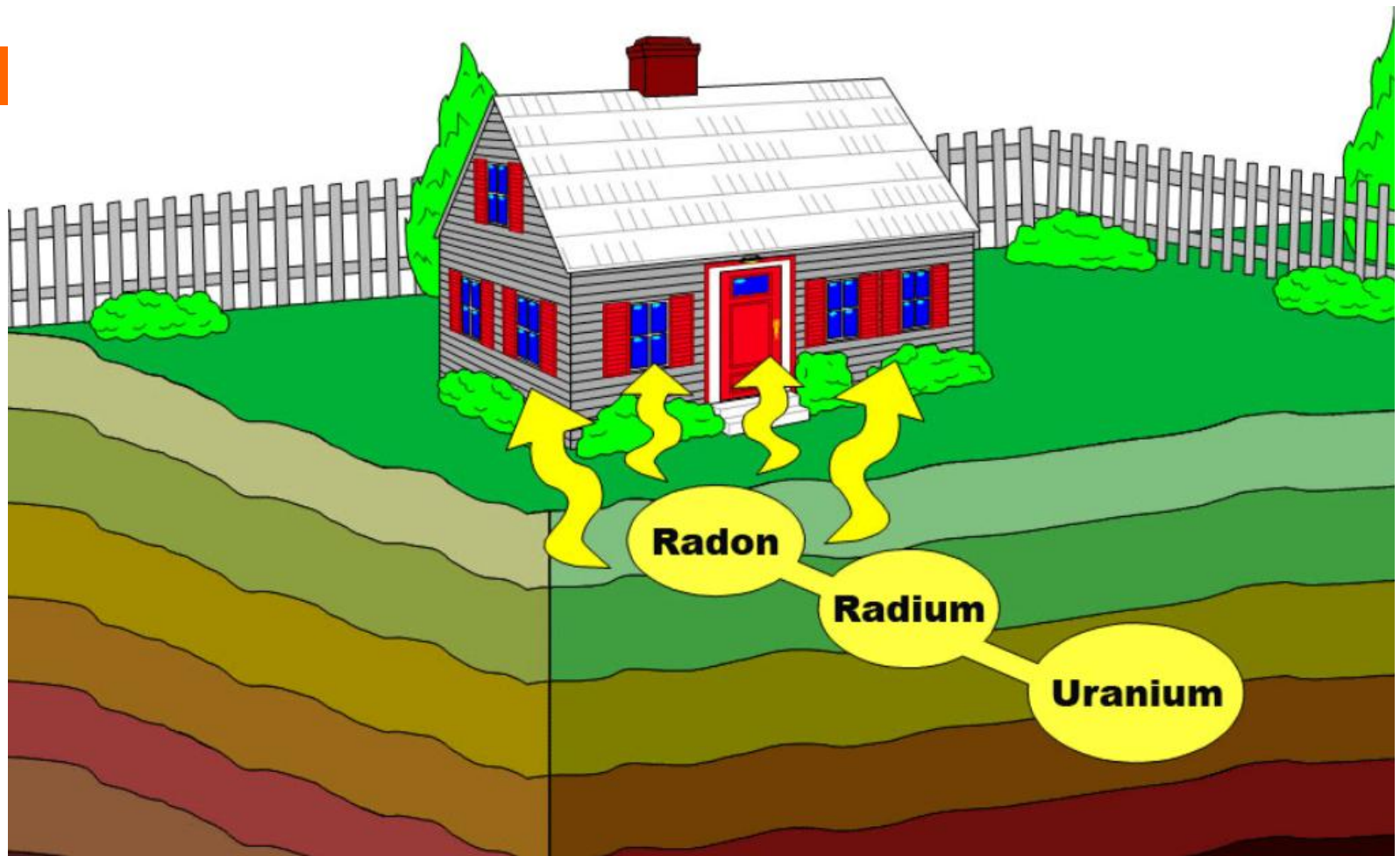
Medicine 11%

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

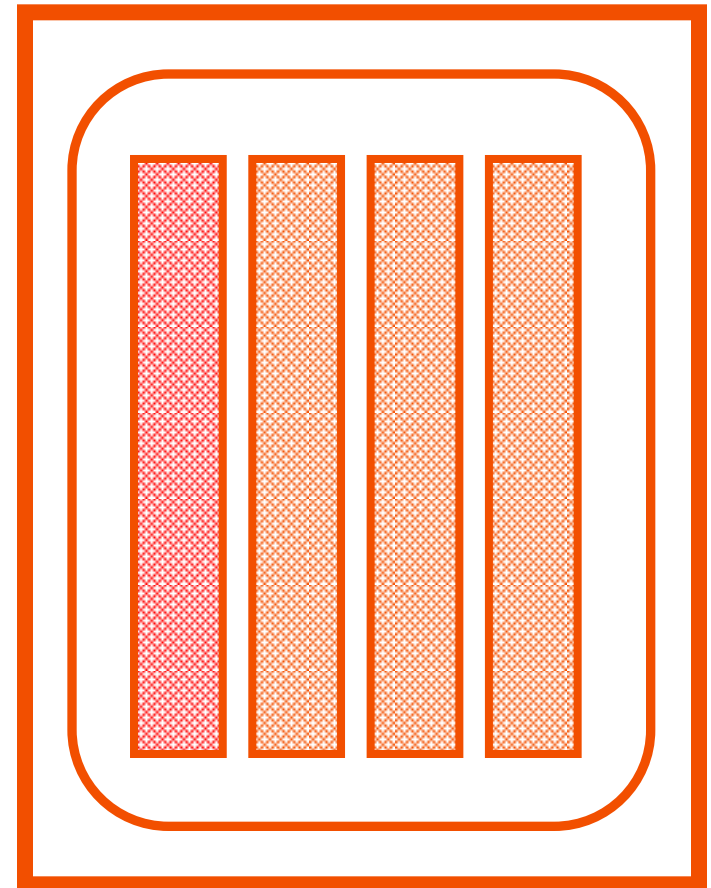
**Deep protection = means to achieve the basic objective of safety**

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.

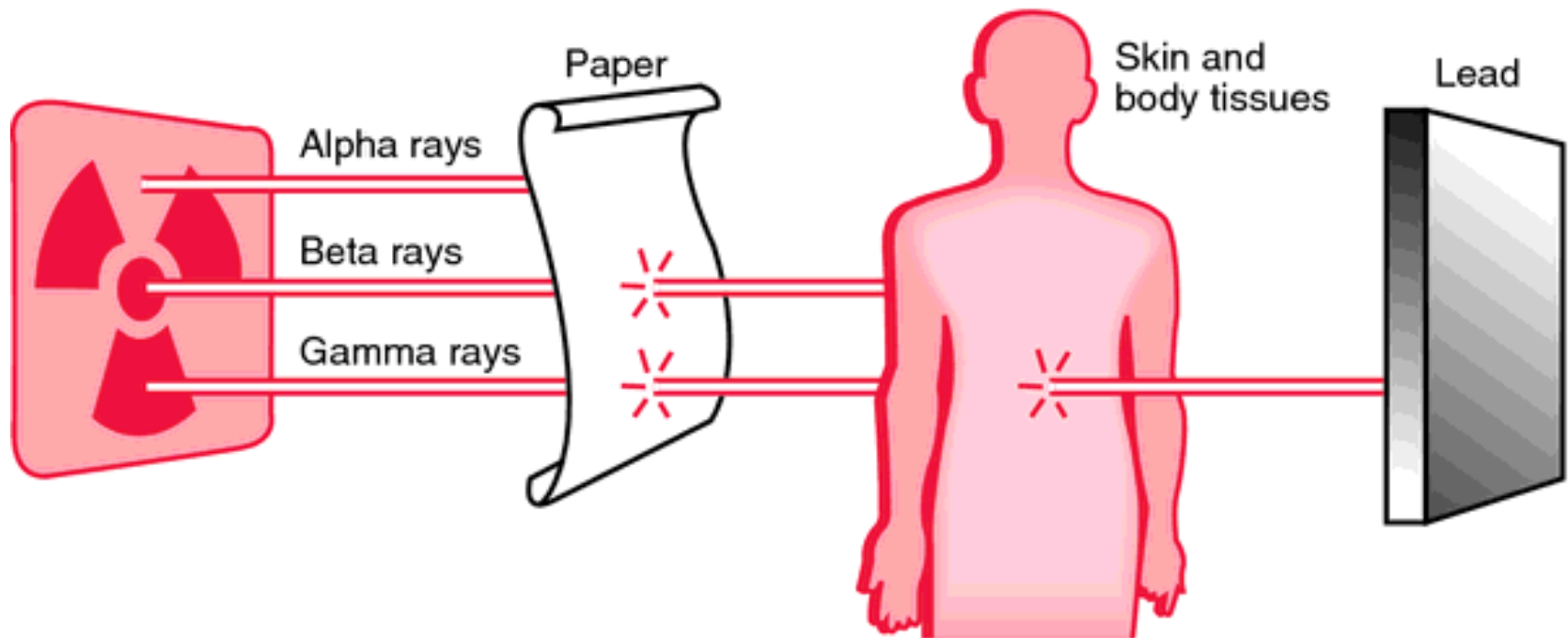
# Protection against radiation

**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

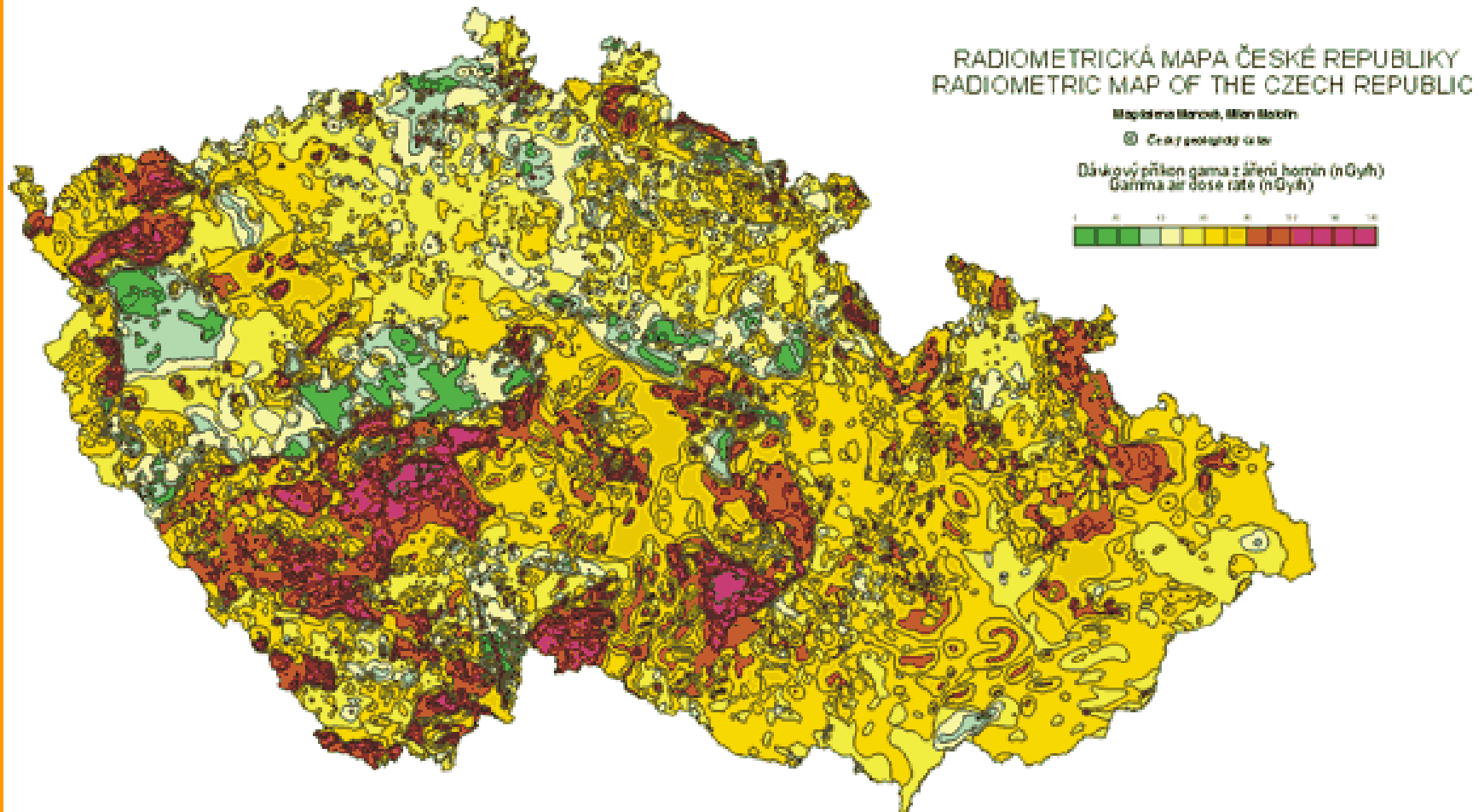
To ensure that during normal operation the radiation exposure inside the device and/or the release of radioactive materials into the environment is as low as reasonably achievable, taking into consideration economic and social factors and prescribed limits and ensure mitigate the extent of exposure to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

## The principle of ALARA

Observe the rules and seek new and better ways of performing work  
Already applied in the design

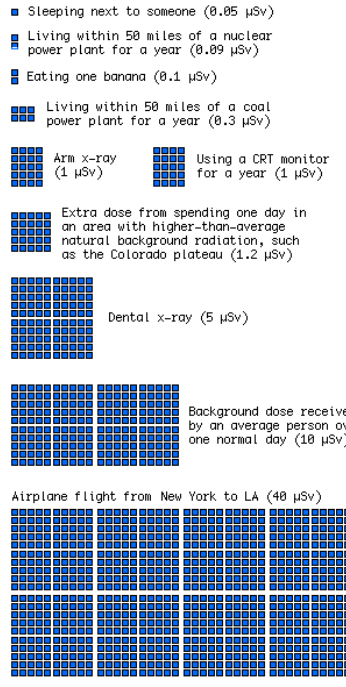
Czech Republic  
Iran (Ramsar)  
India (Kerala)  
Brazil (Guarapari)

- cca 3 mSv/year
- up to 400 mSv/year
- up to 17 mSv/year
- up to 175 mSv/year



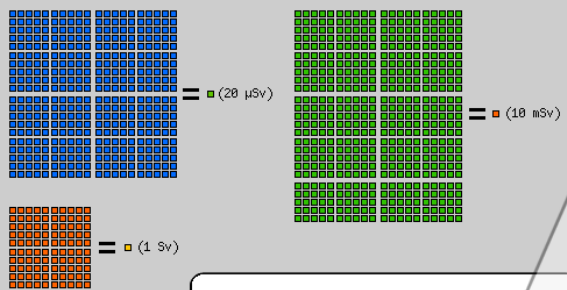


# Protection



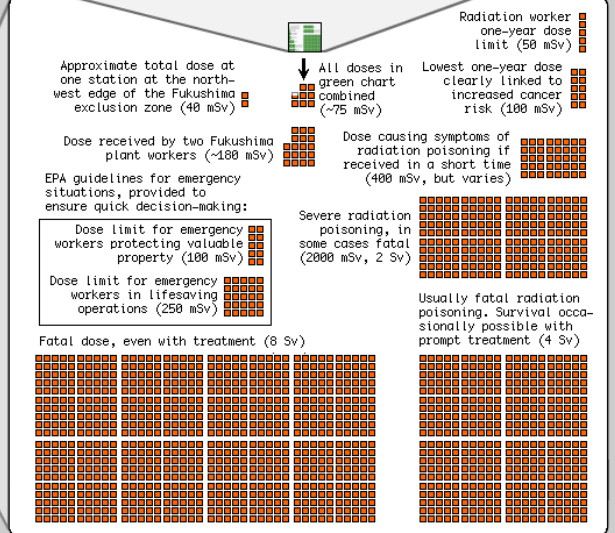
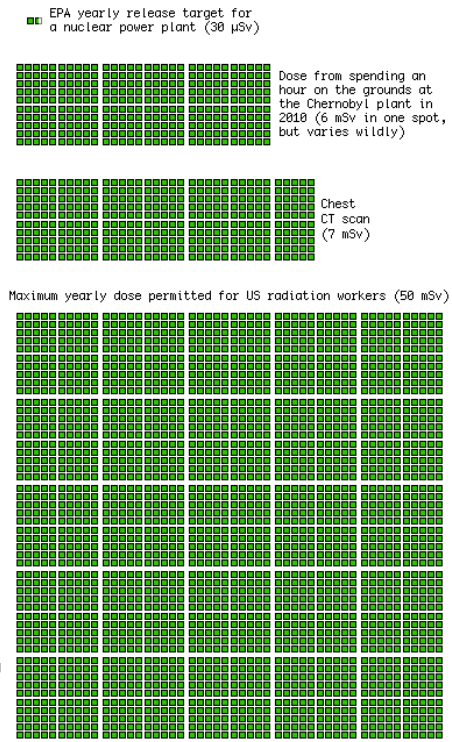
■ Using a cell phone (0  $\mu$ Sv)—a cell phone's transmitter does not produce ionizing radiation\* and does not cause cancer.  
\* Unless it's a banana phone.

■ = (0.05  $\mu$ Sv)



Ten minutes next to the Chernobyl reactor core after explosion and meltdown (50 Sv)










Sources:  
<http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/>  
<http://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/dose_calculator.cfm)  
[http://www.deq.idaho.gov/inl\\_oversight/radiation/radiation\\_guide.cfm](http://www.deq.idaho.gov/inl_oversight/radiation/radiation_guide.cfm)  
<http://mitnse.com/>  
[http://www.bnl.gov/bnlweb/PDF/03SEB/Chapter\\_8.pdf](http://www.bnl.gov/bnlweb/PDF/03SEB/Chapter_8.pdf)  
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[http://www.next.gov.jp/component/a\\_menu/other/detail/\\_icsFiles/afieldfile/2011/03/18/1303727\\_1716.pdf](http://www.next.gov.jp/component/a_menu/other/detail/_icsFiles/afieldfile/2011/03/18/1303727_1716.pdf)  
<http://radiology.rsna.org/content/248/1/254>



# Porovnání ra

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

# Radiation Dose to Patients From Common Imaging Examinations

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.

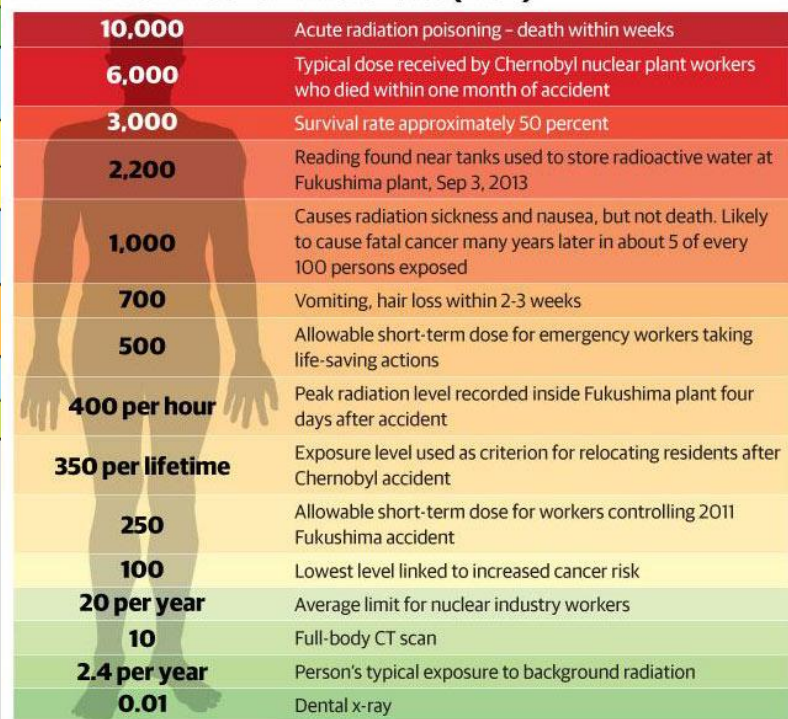
**Important:** Pediatric patients vary in size. Doses given to pediatric patients will vary significantly from those given to adults.

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.

## RADIATION DOSAGE CHART

.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)

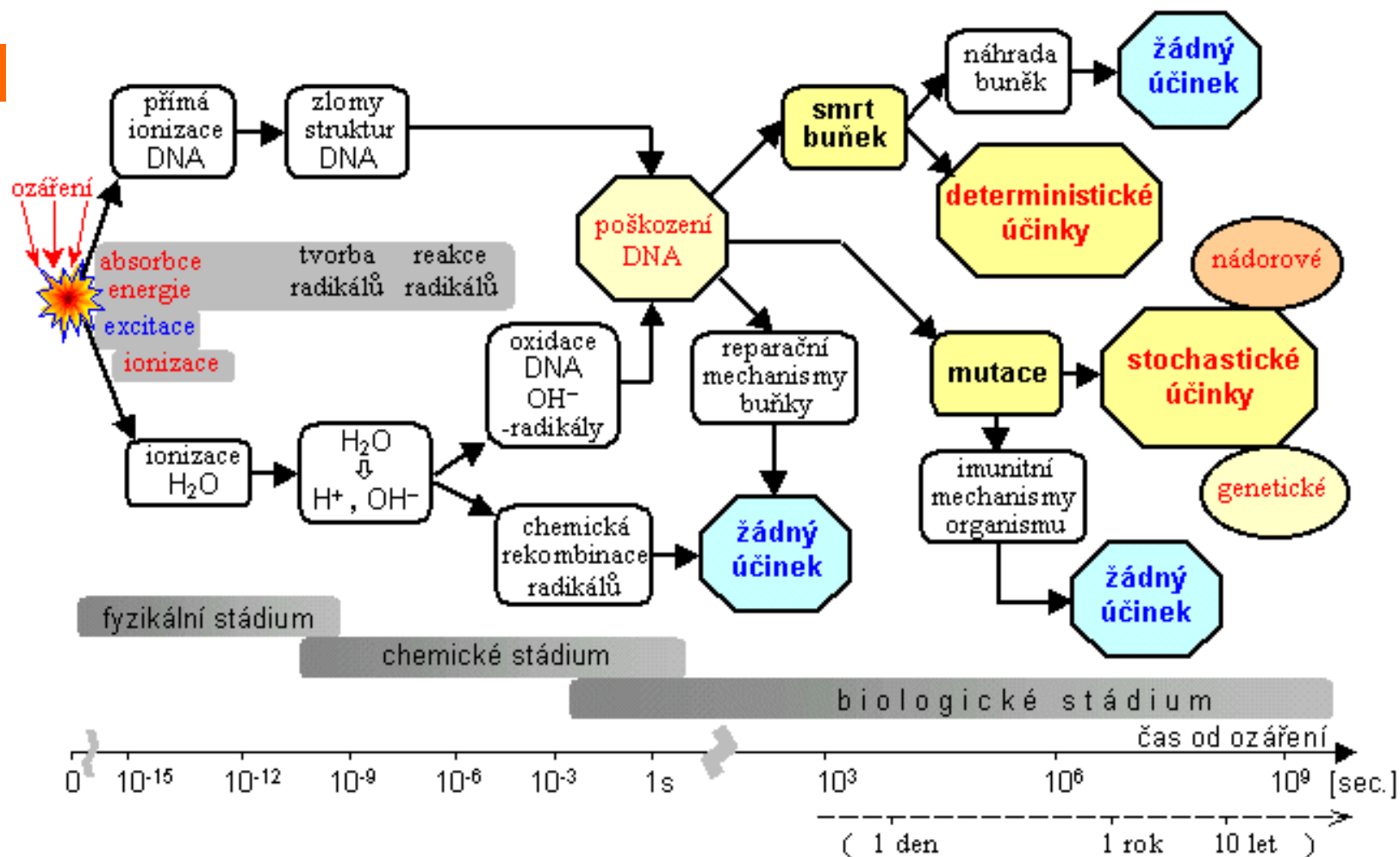


Long distance flights in 10 km altitude  
= ca. 4  $\mu\text{Sv/hod}$





# 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**

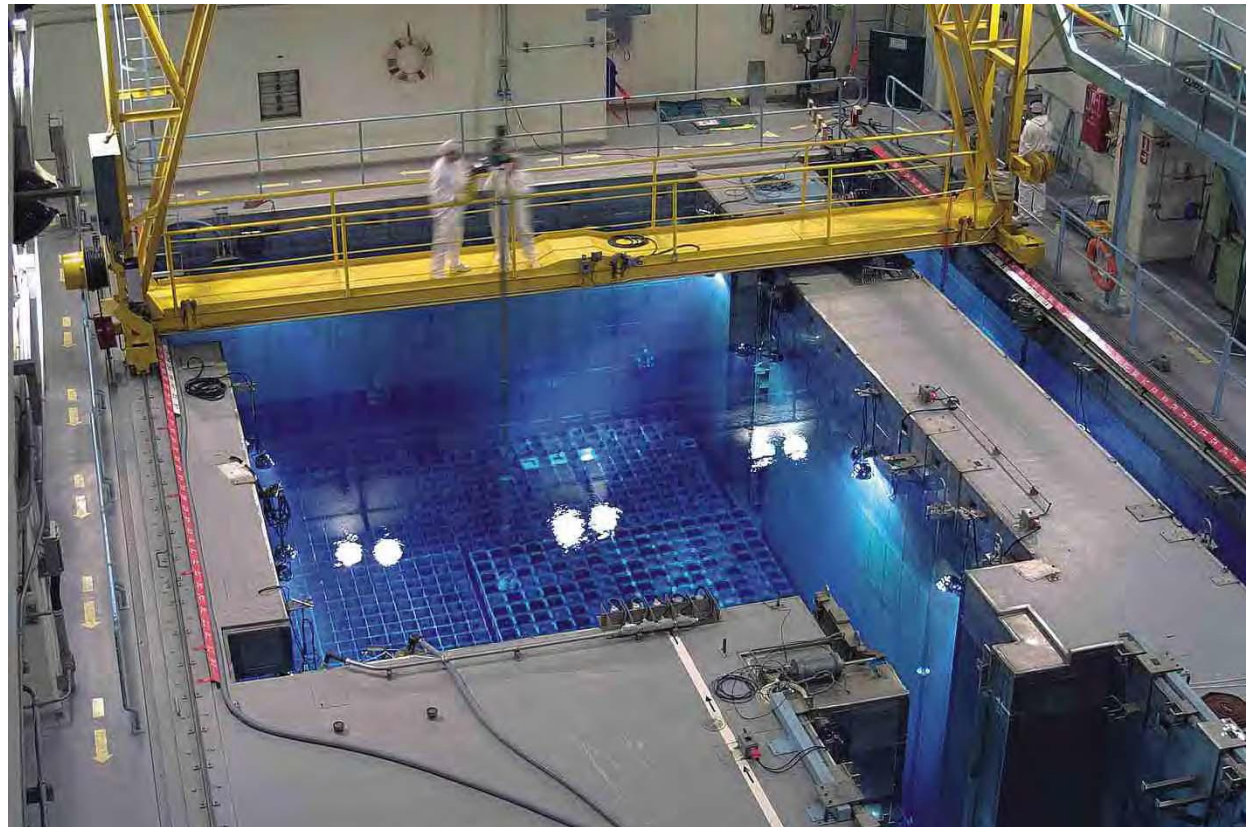
**Protection from flood and adverse meteorological phenomena**

**Protection against pressure waves from explosions**

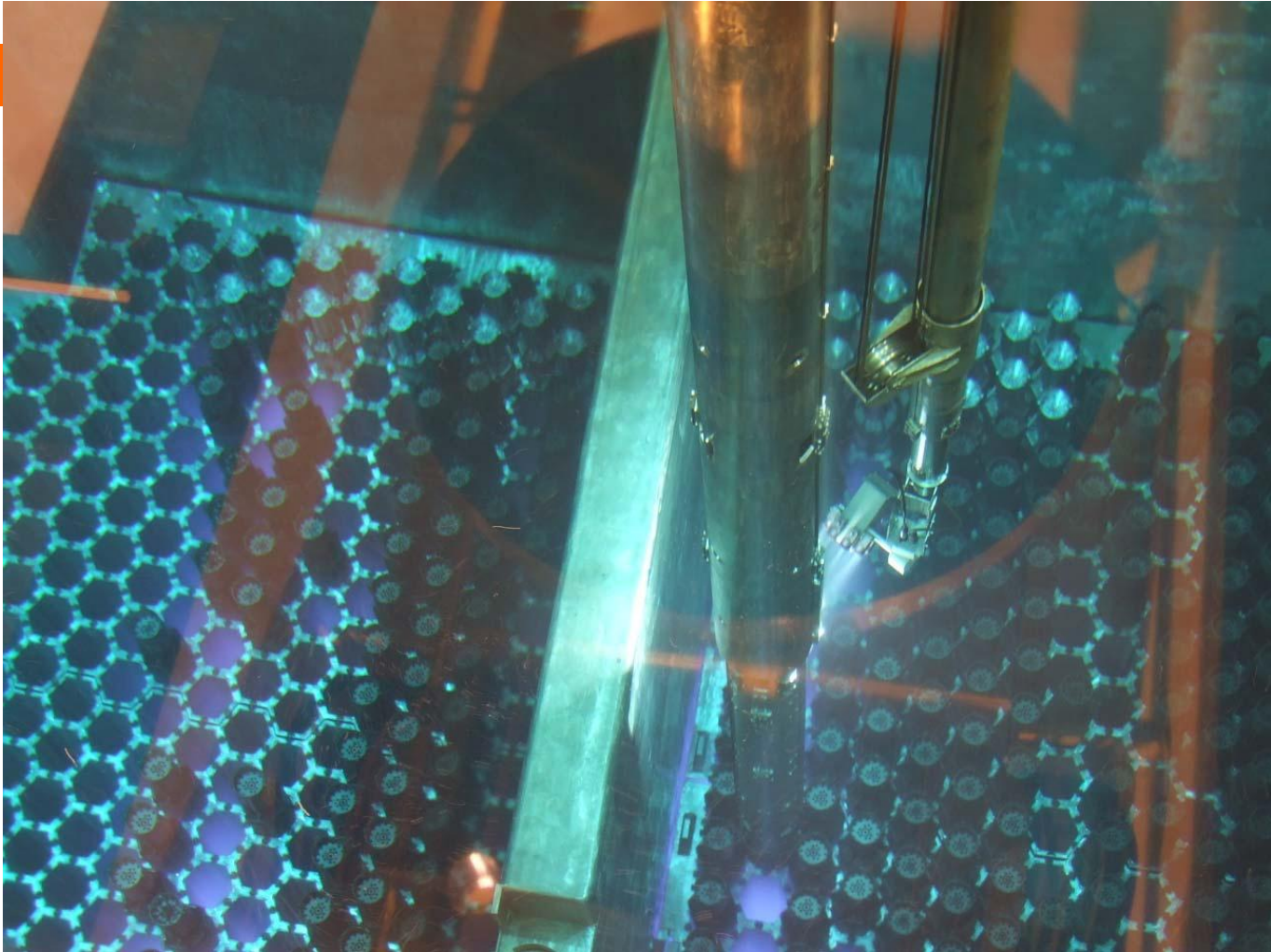
**Protection against the effects caused by the fall of the aircraft**

**Protection against the influence of third parties**

# Storage



# Storage





# Storage





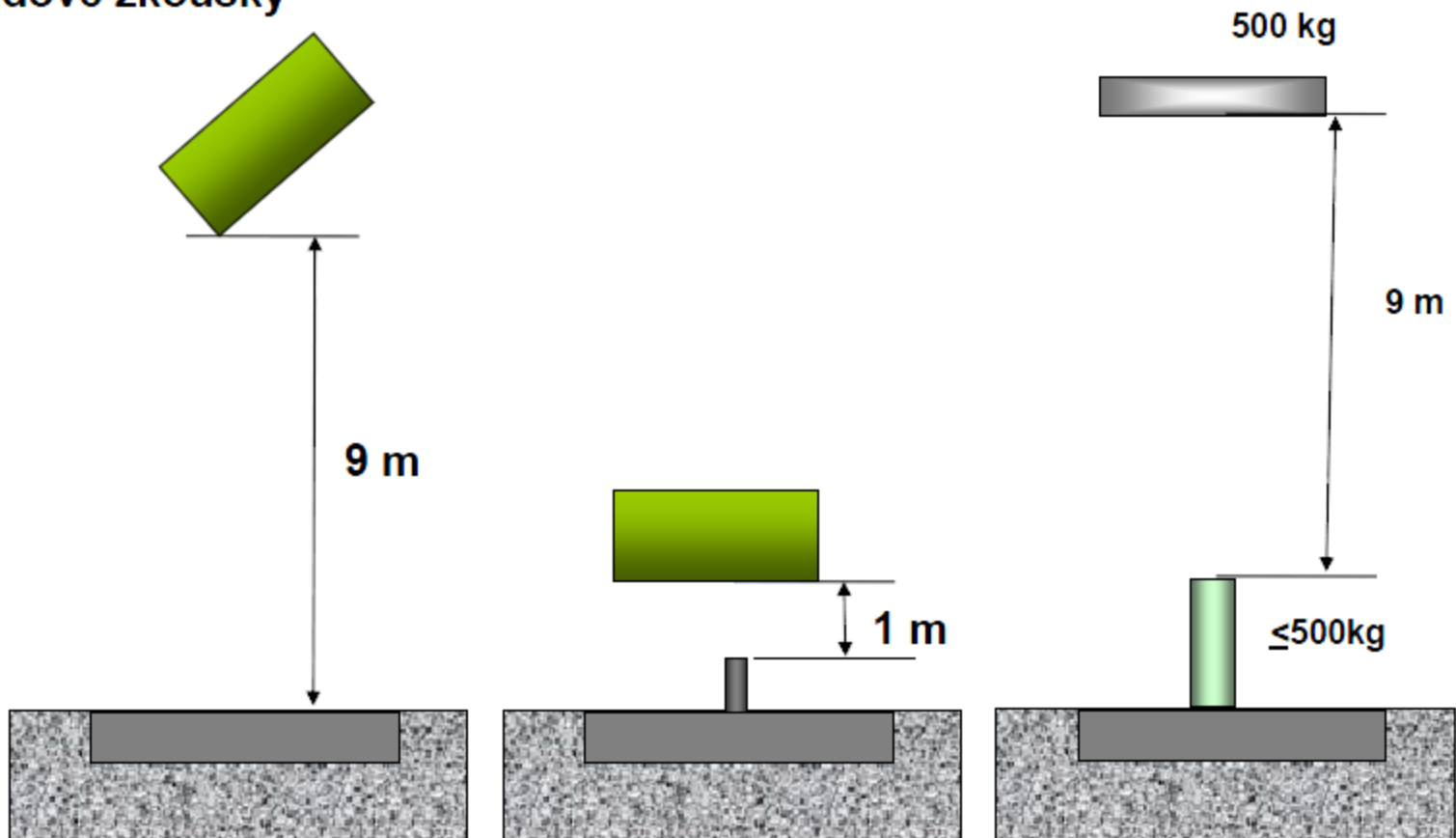
# Storage



# Storage

Zkoušky prokazující schopnost přestát podmínky nehody při přepravě

- Pádové zkoušky



# Storage

Zkoušky prokazující schopnost přestát podmínky nehody při přepravě

- Požár
- Ponoření

