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# Radionuclides of natural and artificial origin

Fernando P. Carvalho

The Environmental Science Education for Sustainable Human Health

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# Environmental Radiation Protection

## Radionuclides of natural and artificial origin

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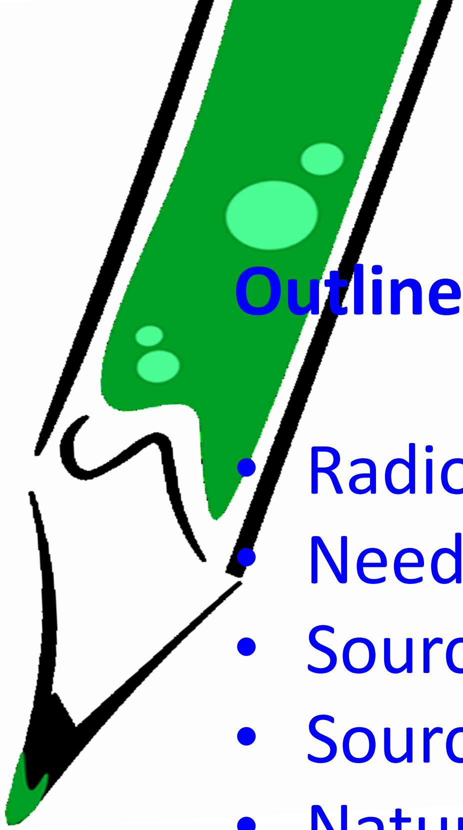


# Outline

- Radioactivity and ionizing radiation
- Need for protection against ionizing radiations
- Sources of natural radioactivity
- Sources of artificial radioactivity
- Naturally-occuring radioactive materials (NORM) and non-nuclear industries
- Environmental monitoring for radiation protection of the population

# Radioactivity and Ionizing Radiation

# TERMINOLOGY

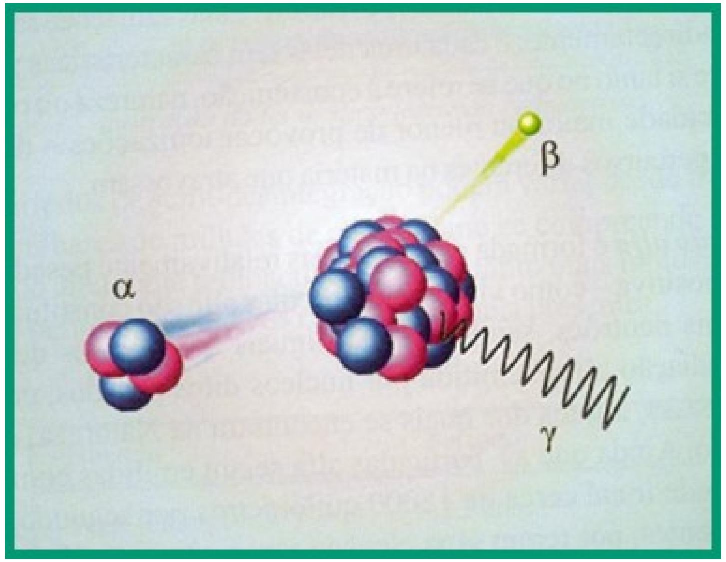
**Radionuclides:** Unstable nuclides

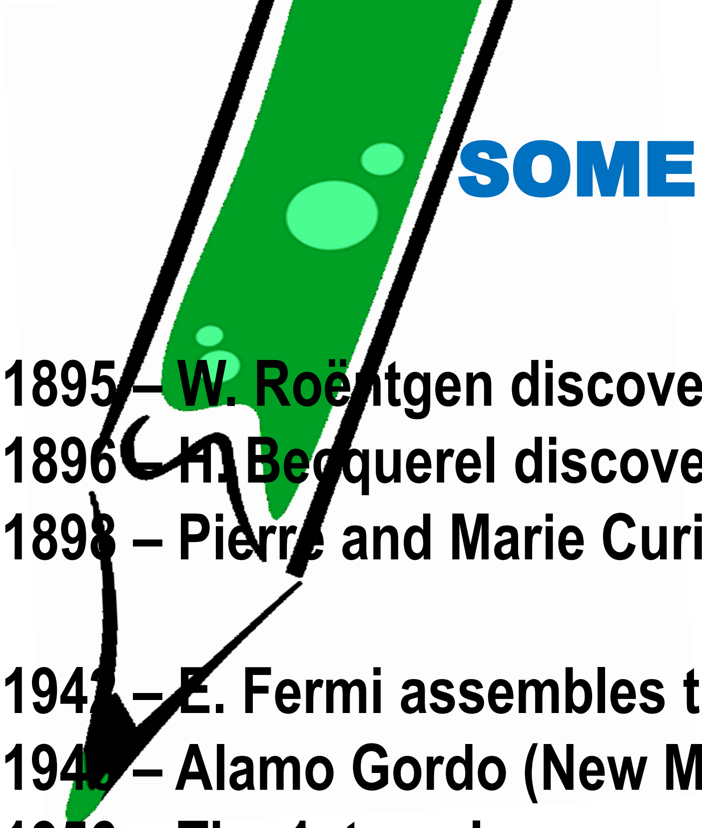
**Radioactivity:** Nuclear transformation of unstable nuclides with emmission of radiation (energy or particles)

**Ionizing radiations:** Alpha (α), Beta ( β), Gamma ( γ) , neutrons (n), X-ray

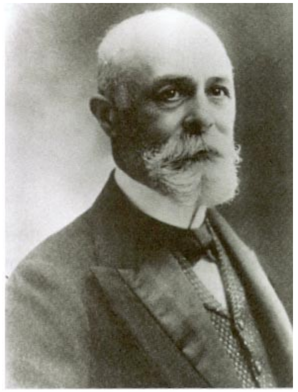
**Activity:** Decay rate of a radionuclide, or disintegrations per second (1 Bq = 1 dps)

**Half-life:** Time to decrease to half activity of a given radionuclide





# SOME HISTORICAL DATES



Antoine-Henri Becquerel

Marie Curie

1895 – W. Roëntgen discovers X-rays
1896 – H. Becquerel discovers radioactivity
1898 – Pierre and Marie Curie isolate Radium (226Ra) and Polonium (210Po)

1942 – E. Fermi assembles the 1st nuclear reactor (controlled chain reaction)
1945 – Alamo Gordo (New Mexico), testing of the first nuclear bomb
1956 – The 1st nuclear power plant for electricity production starts operating

1986 – Accident at the Chernobyl nuclear power plant.
2011 - Accident at the Fukushima Nuclear Power Plan


*Nobel Prise 1902*

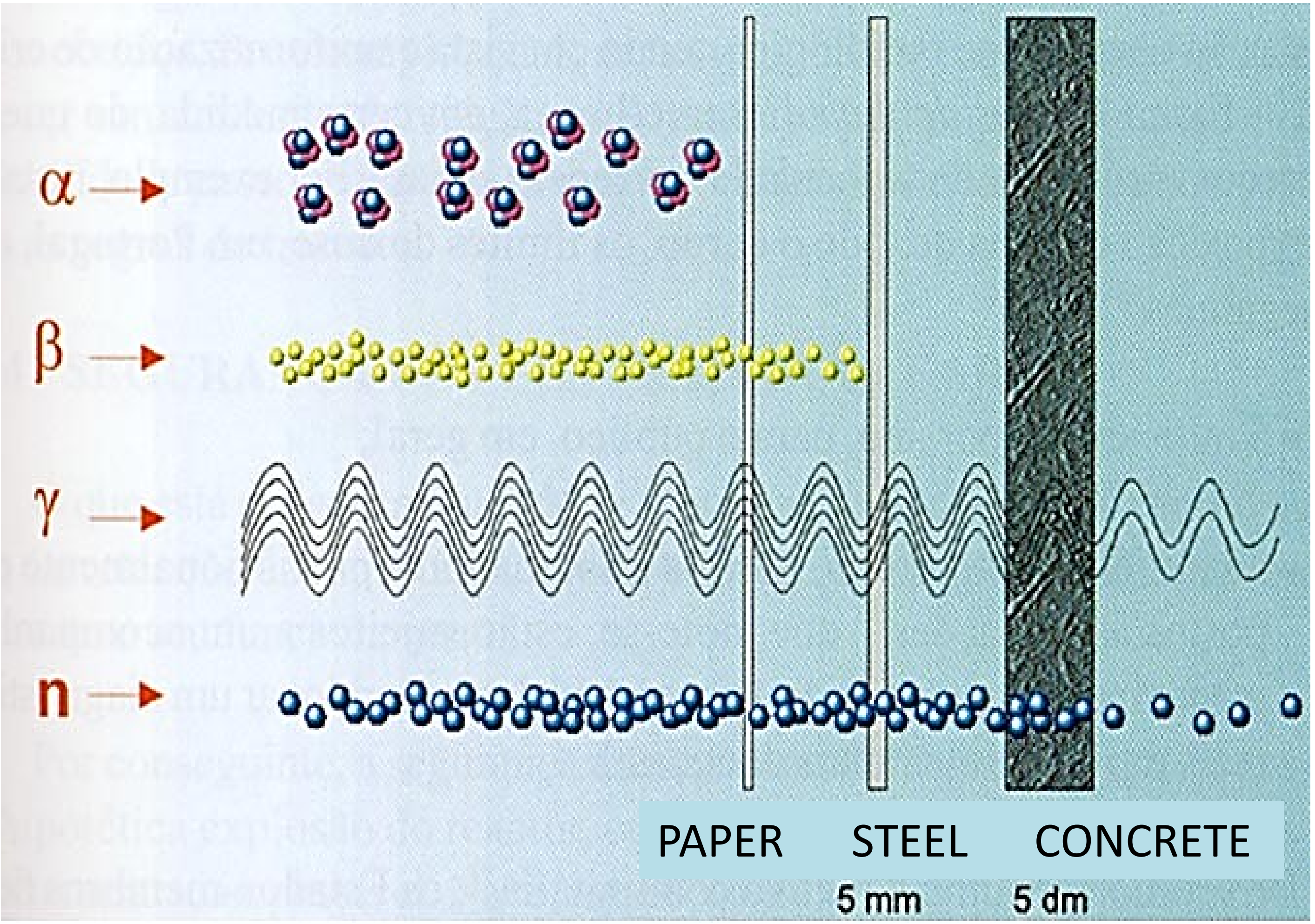
# RADIOACTIVITY AND IONIZING RADIATIONS

Weighting factor of radiations regarding biological effects:

X-ray,  γ,  β  = 1

n = 5-20 (depending on energy)

α = 20




***Penetration of radiation in materials depends on the type of radiation and composition of materials***

# APPLICATIONS OF RADIATIONS AND RADIOISOTOPES

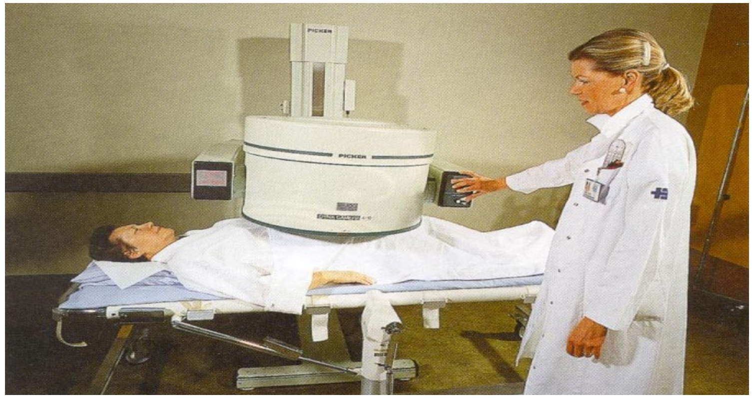
**X-Rays**

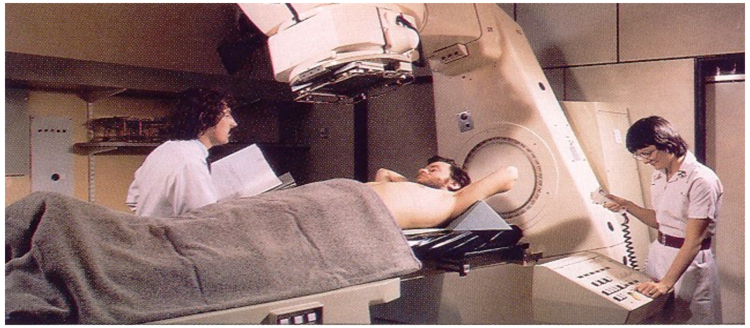
Radiography, Radiology,
Radiosterilization

**OCCUPATIONAL EXPOSURE:**
**exposure of workers to radiation at the workplace**

**Radioisotopes in medicine**

Iodine-128, Technetium-99m,
Actinium-225, Cobalt-60

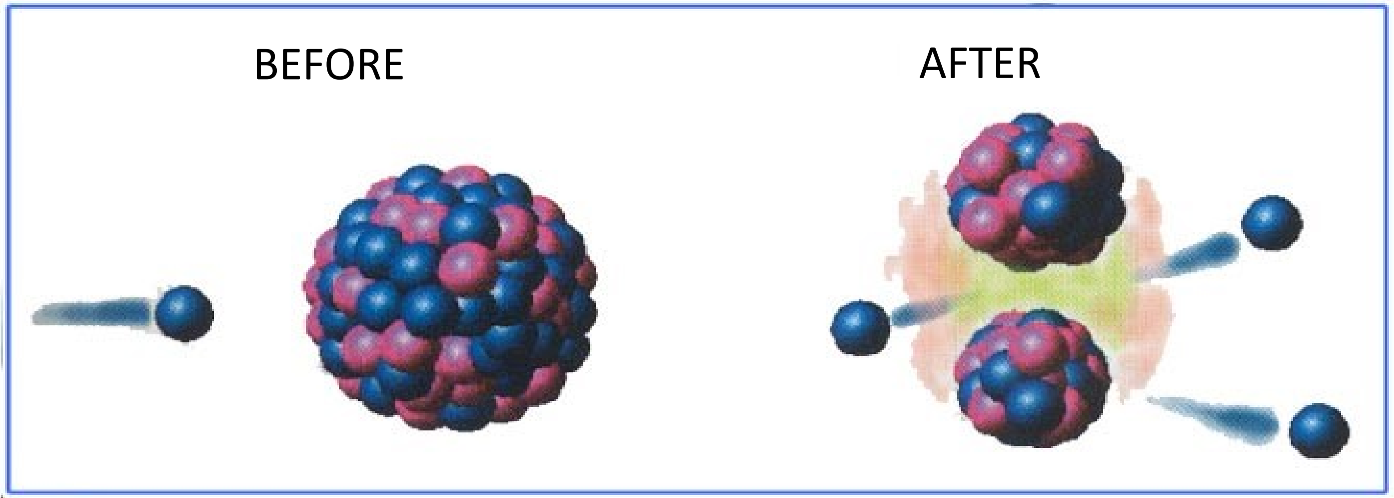




**Radioisotopes in industry**

Iridium-192, Kripton-85,
Cesium-137, Selenium-75

# URANIUM ATOM FISSION




*Representation of a nuclear fission reaction*

- The discovery of the fission of the **uranium** atom started a new epoch, the atomic age
- The production of radioisotopes has started numerous applications in medicine, industry and agriculture.

# APPLICATIONS OF ATOMIC FISSION

Nuclear weapons:
nuclear tests
$^{137}Cs$, $^{90}Sr$, $^{131}I$, $^{144}Ce$, …
$^{3}H$, $^{14}C$

Electricity generation:
nuclear power plants
$^{60}Co$, $^{65}Zn$, $^{110}Ag$, $^{137}Cs$,
$^{239,240}Pu$, $^{241}Am$, ...
$^{3}H$

**ENVIRONMENTAL EXPOSURE:**

► artificial radionuclides dispersed in the environment

► radiation exposure through environmental pathways

# Exposure to ionizing radiation
# Protection against ionizing radiation

# SOURCES OF IONIZING RADIATIONS

Cosmic radiation

14C,3H, 7Be

Internal sources

40K, 226Ra, 210Pb, 210Po, 14C, U, Th

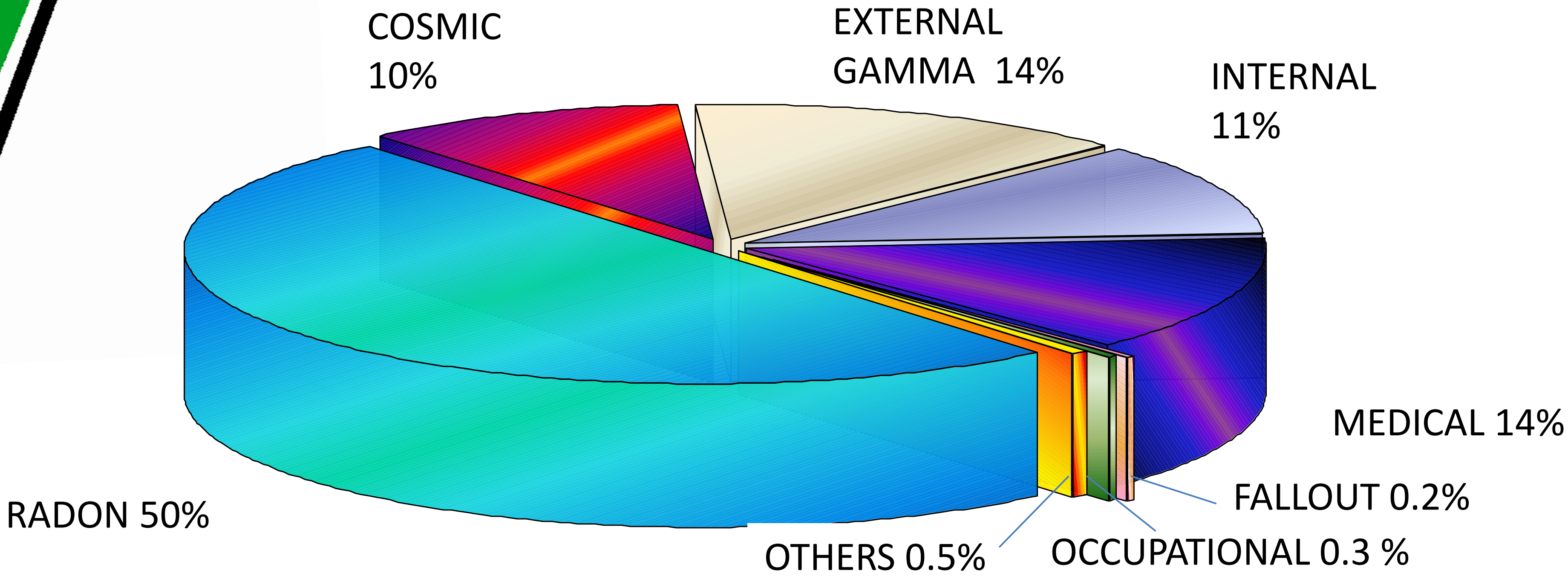
Terrestrial radiation

(More than 60 radioisotopes are part of the earth's crust)

… Living beings formed and evolved in the presence of radioactivity

# AVERAGE POPULATION EXPOSURE

Natural and artificial radiation
from all sources

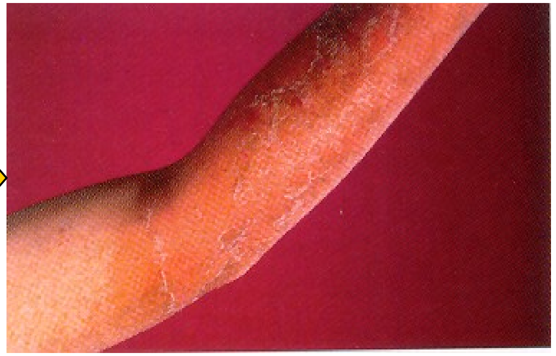



Average individual dose 2.4 mSv/a

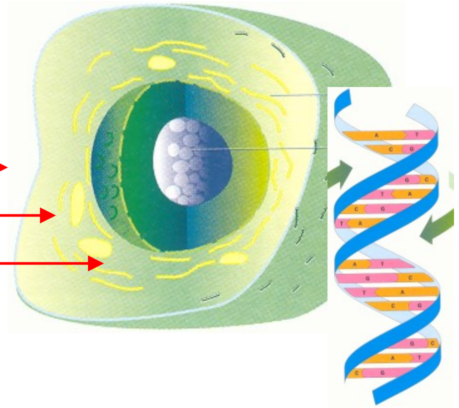
# BIOLOGICAL EFFECTS OF IONIZING RADIATIONS

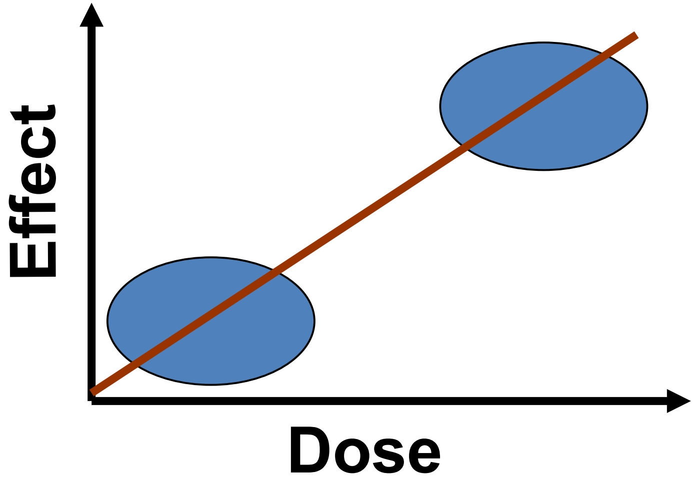
Health Effects:

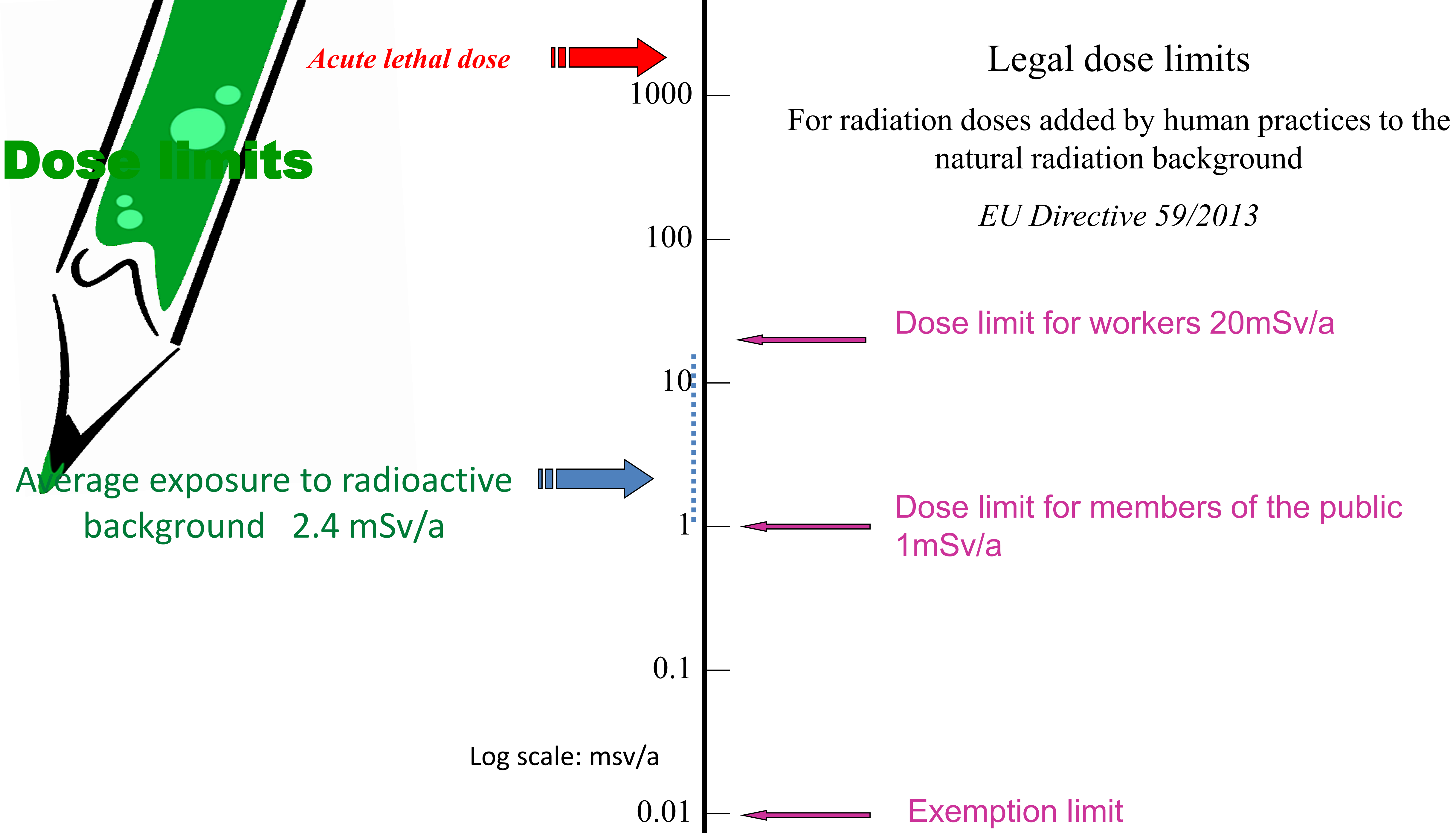
- **Immediate effects**: exposure to high doses causes damage to human tissue and produces deterministic effects.

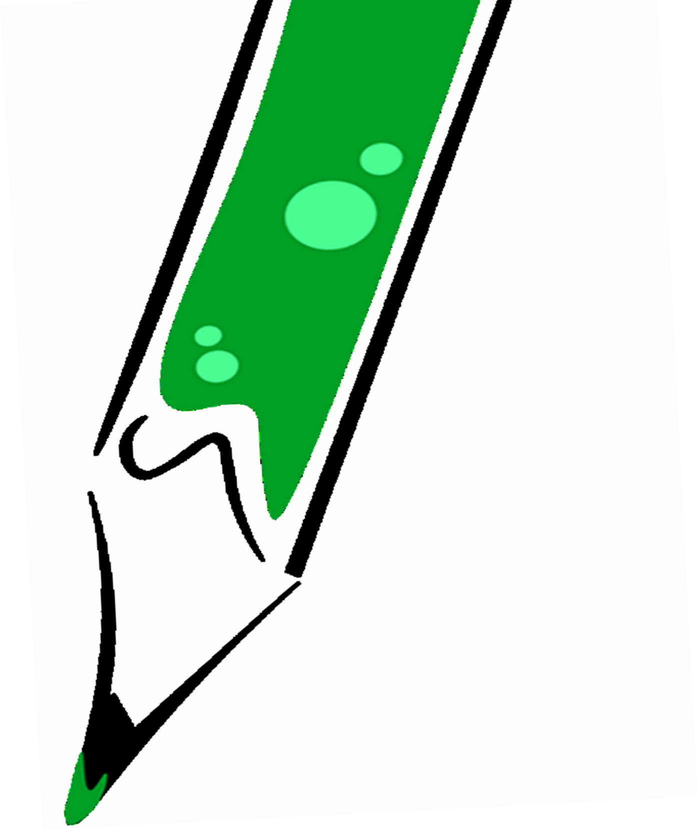


- **Long-term effects**: exposure to low doses can cause delayed cancer (latency 15-20 years) and hereditary damage. These effects are probabilistic.





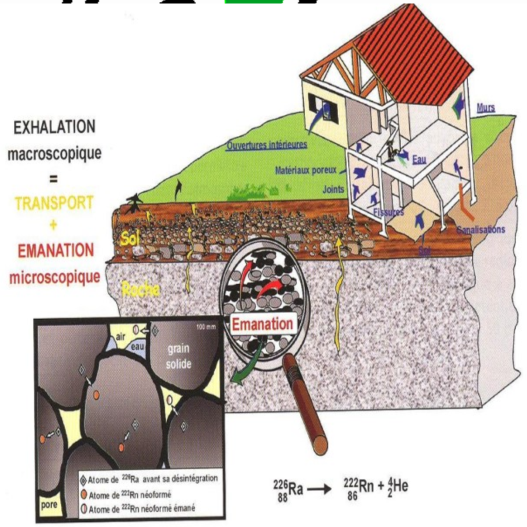

Dose limits
Acute lethal dose
Legal dose limits
For radiation doses added by human practices to the natural radiation background
EU Directive 59/2013
1000
100
Dose limit for workers 20mSv/a
10
Average exposure to radioactive background 2.4 mSv/a
1
Dose limit for members of the public 1mSv/a
0.1
Log scale: msv/a
0.01
Exemption limit



# Sources of natural radionuclides and exposures

# MAIN ISSUES POSED BY NATURAL RADIOACTIVITY

## Radon gas indoors (homes, workplaces)




Radon formation and sources and pathways of radon from soils to the air. including indoor air

Radon is the 2nd cause of lung cancer.
EU Recommended limit 300 Bq/m3

## Radioactivity in drinking water (groundwater)

WHO, EU screening limits:
Total beta 1 Bq/L
Total alpha 0.5 Bq/L

## Regions with high natural radioactive background

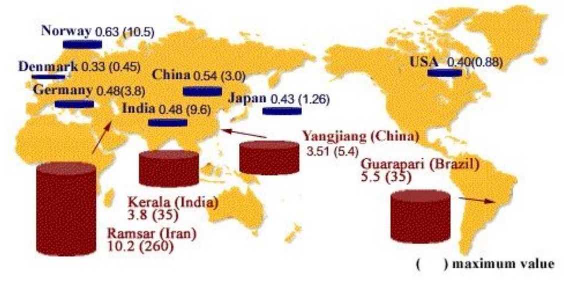
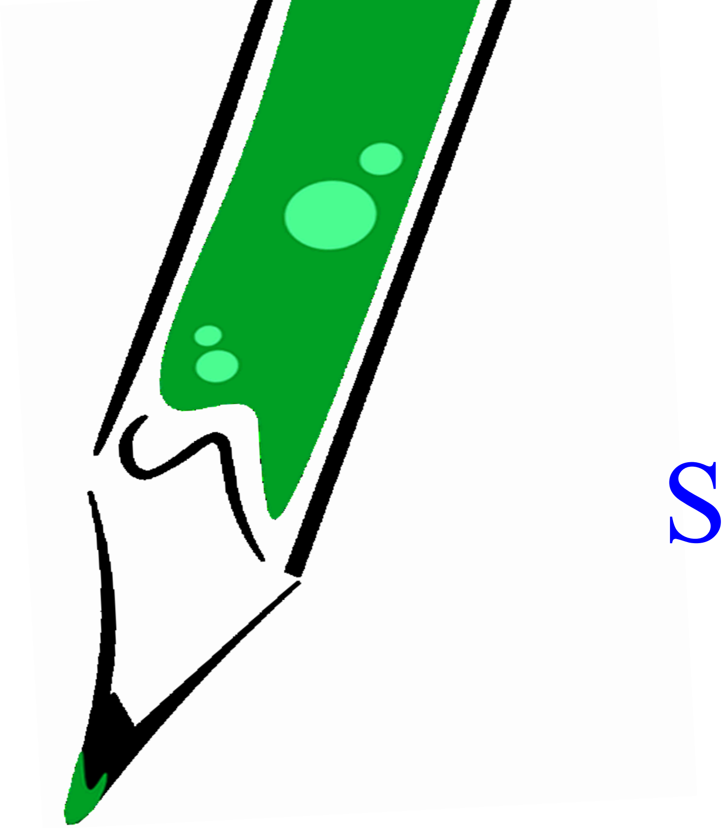
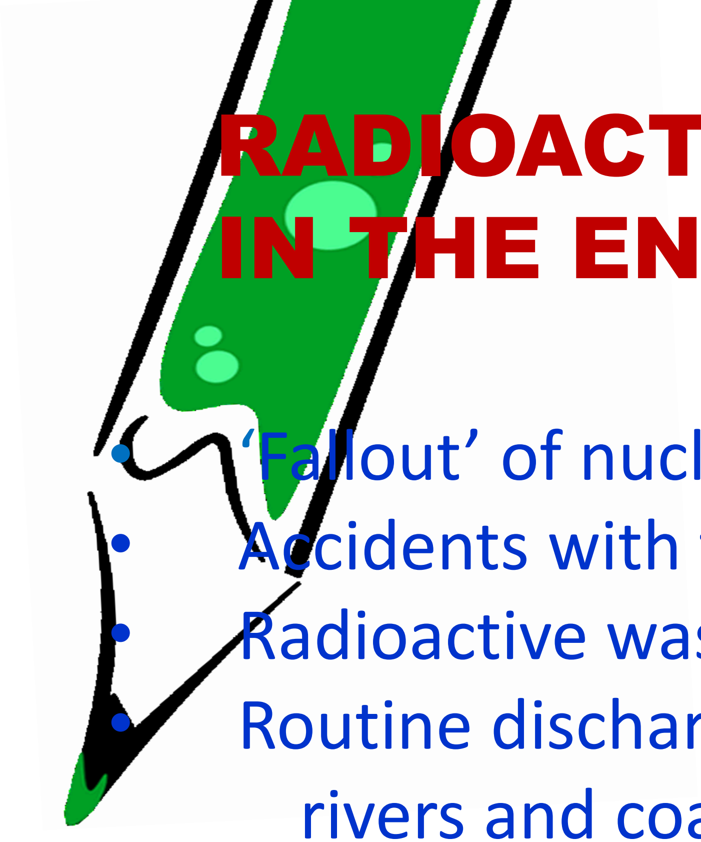



Figure 1. High Background Radiation Areas Around the World. Numbers given are in mSv/year.

External radiation doses may reach 40 to 60 mSv/a.
Biological effects observed in populations.
Not regulated yet.



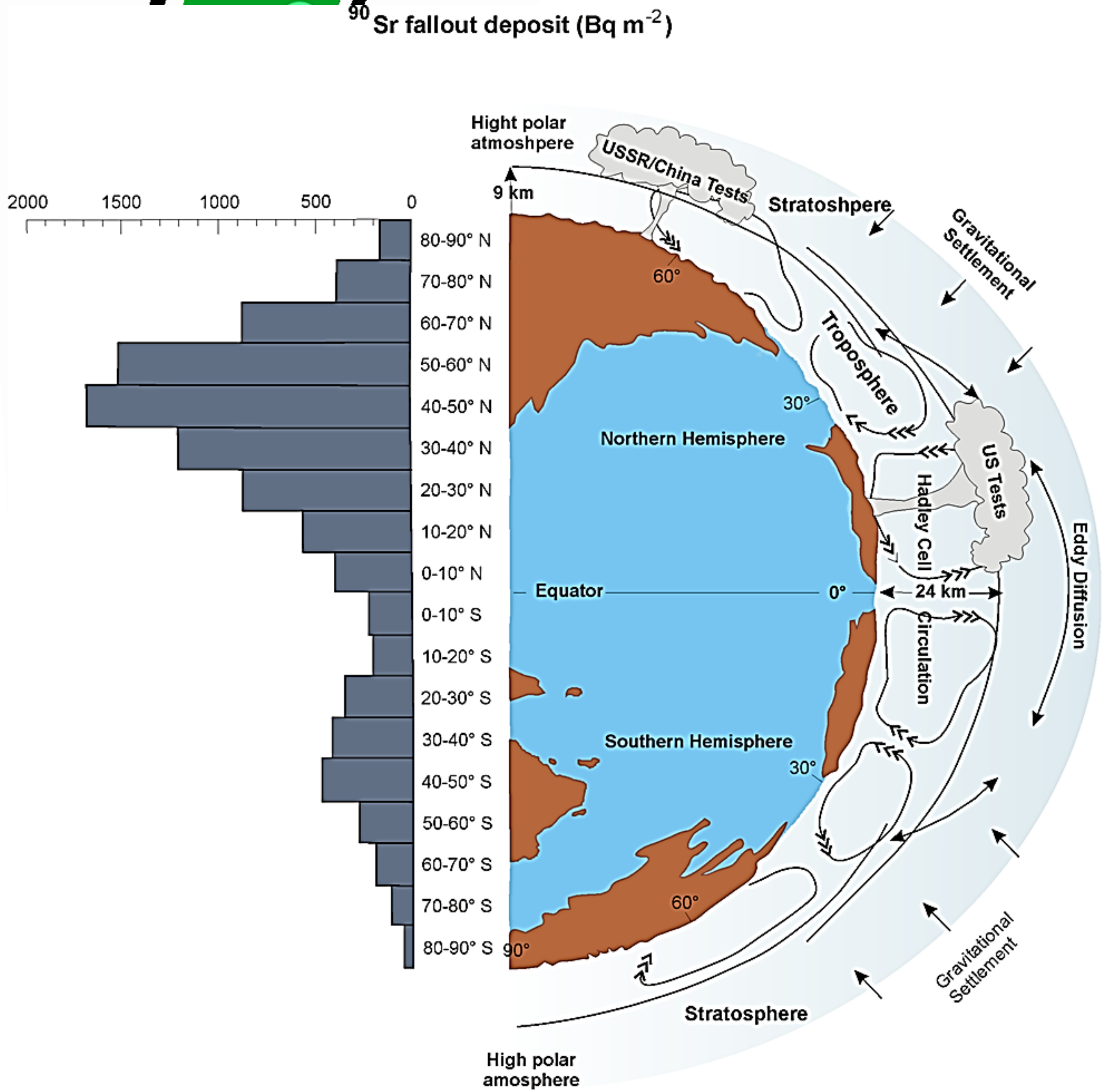
# Sources of artificial radionuclides and exposures



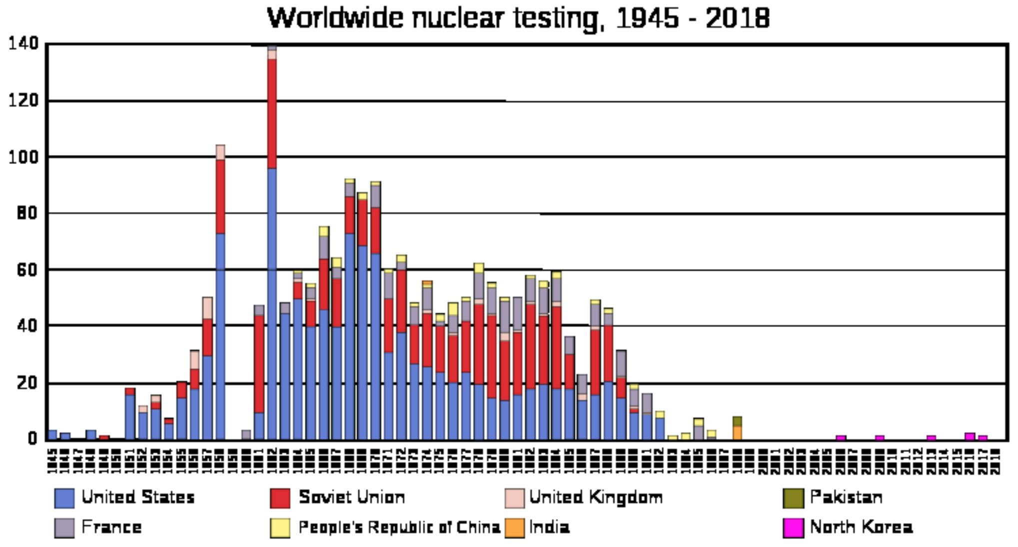
# RADIOACTIVITY FROM ARTIFICIAL ORIGIN IN THE ENVIRONMENT

- ‘Fallout’ of nuclear weapons tests
- Accidents with transport of nuclear materials
- Radioactive waste immersion into the seas
- Routine discharge of radioactive effluents into rivers and coastal seas (hospitals, industries, nuclear power plants)
- Sinking of nuclear submarines and losses of nuclear warheads
- Nuclear accidents

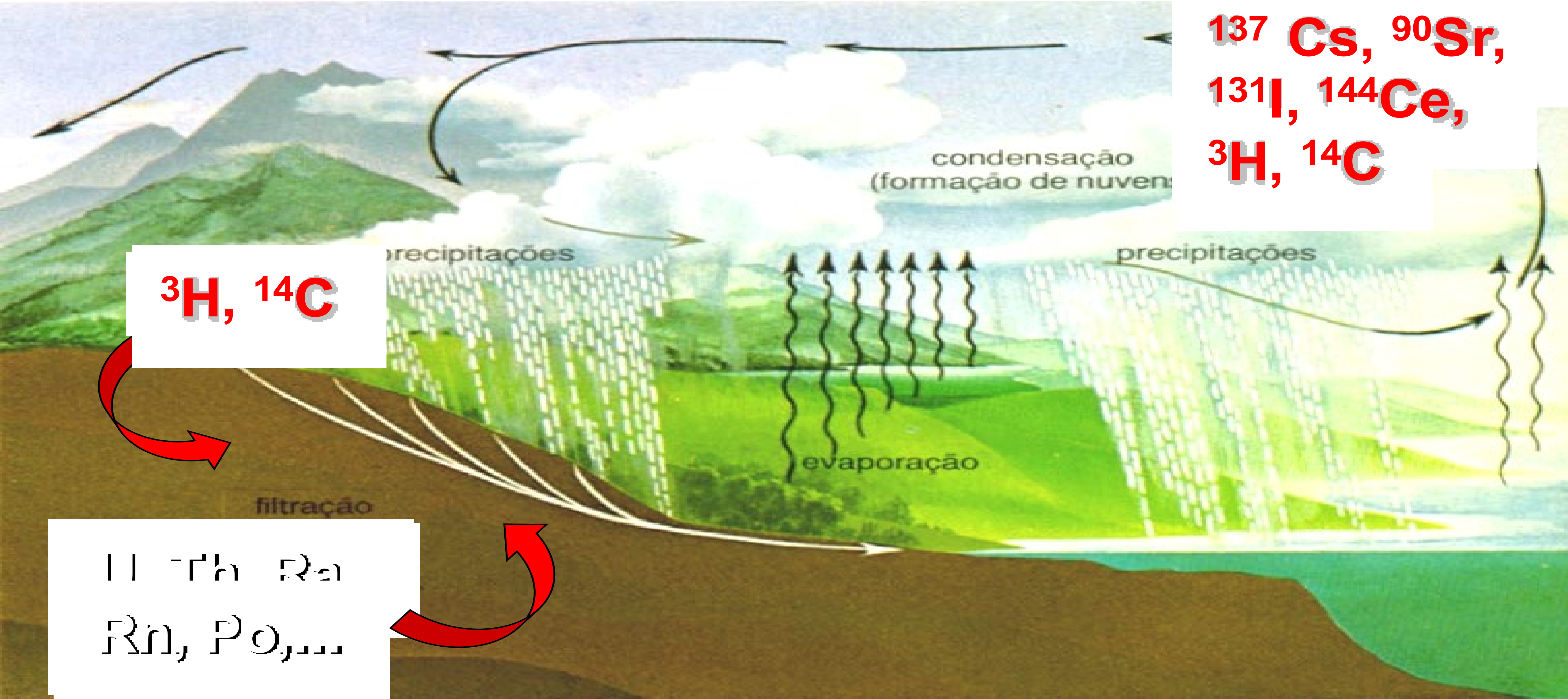
# NUCLEAR TESTS AND ATMOSPHERIC CIRCULATION



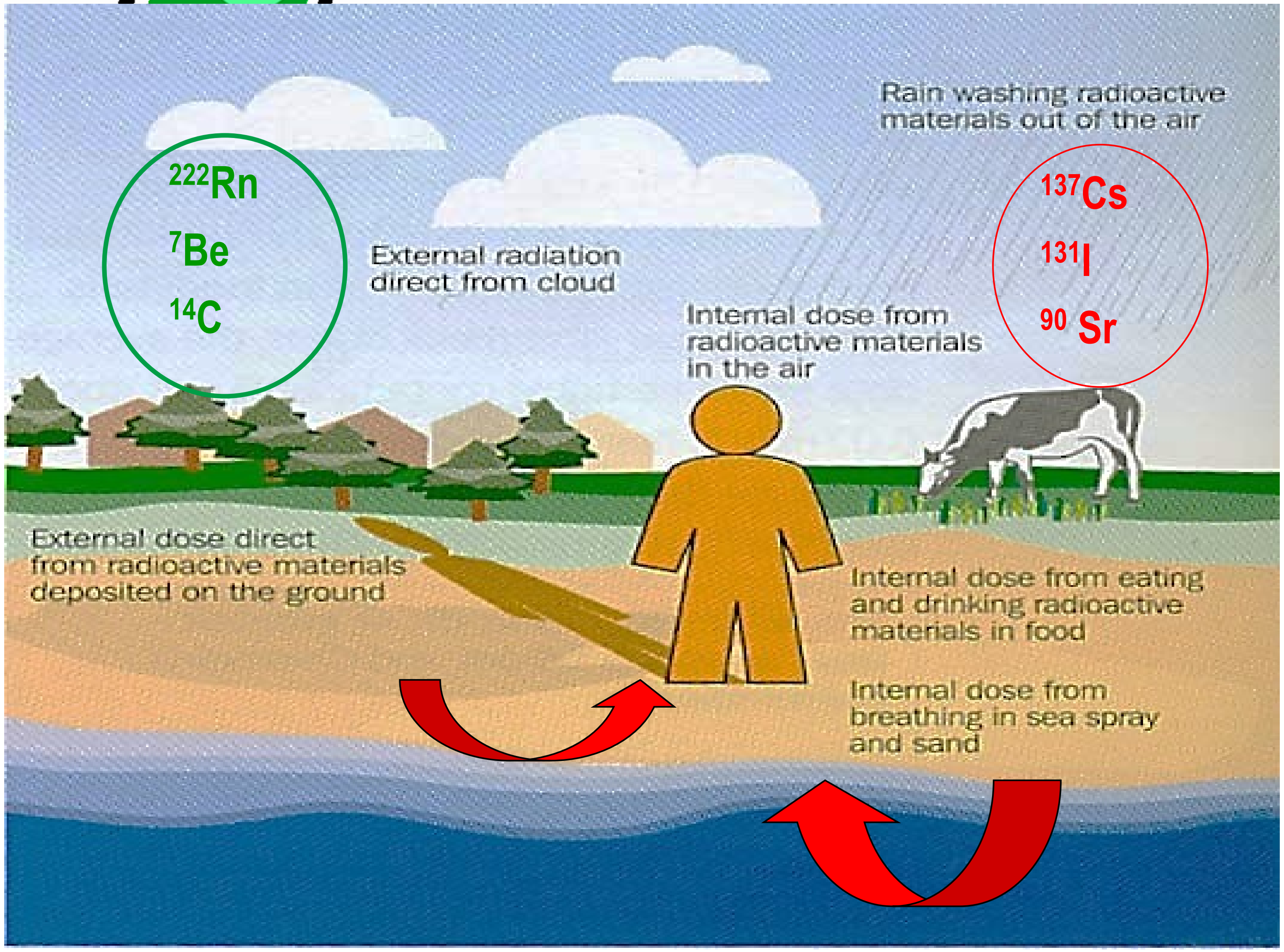

Radionuclides released into the atmosphere are transported by the atmospheric circulation and reach far regions



# Water cycle and radionuclides



# FOOD CHAINS AND RADIONUCLIDES TRANSFER



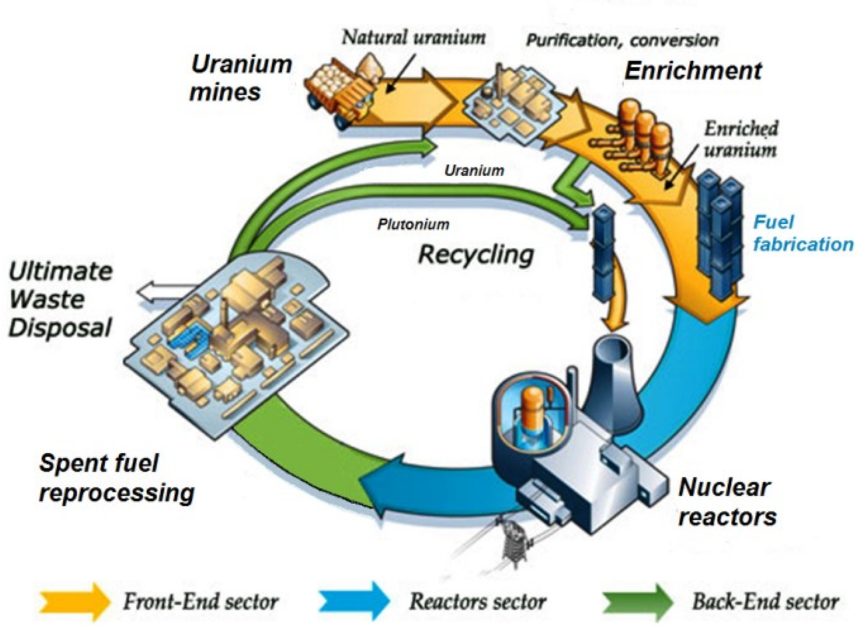

Humans may be exposed to radionuclides through:

- direct **inhalation** from the air
- **ingestion** with food and water
- **external irradiation** by radionuclides in clouds and deposited on the ground

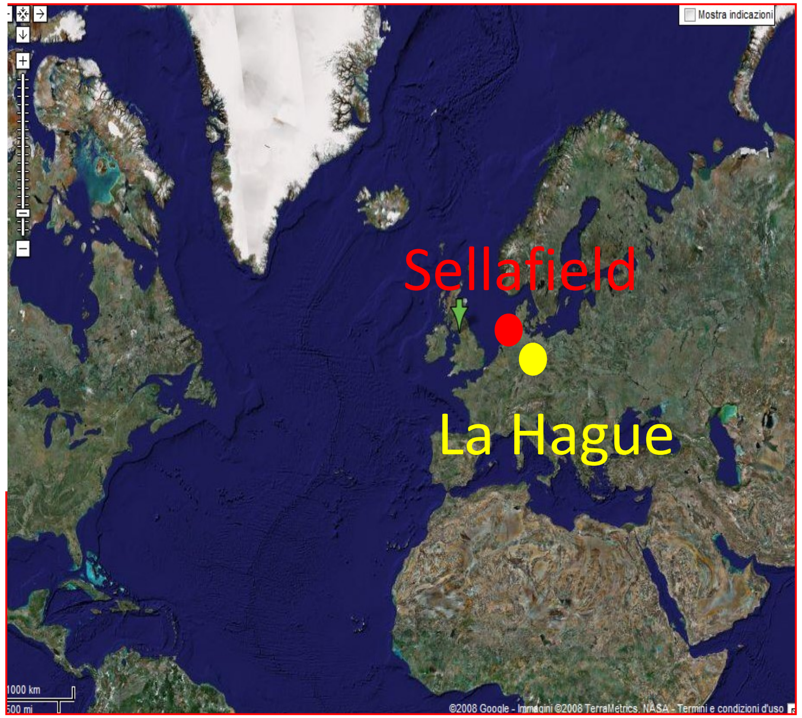
Radionuclides dispersed in the environment may be re concentrated by biota and transfered in the food chains.

# DISCHARGES FROM NUCLEAR FACILITIES

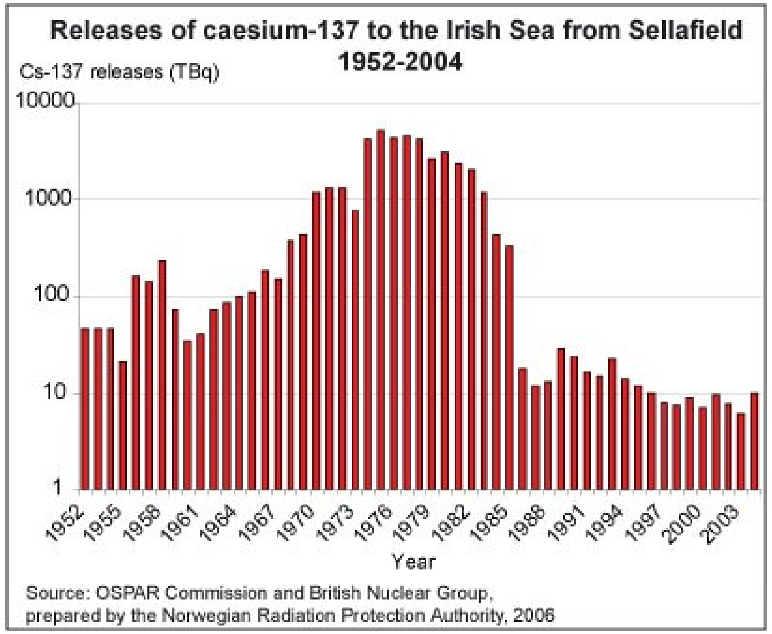
## Nuclear Industry: Reprocessing plants




The nuclear fuel cycle

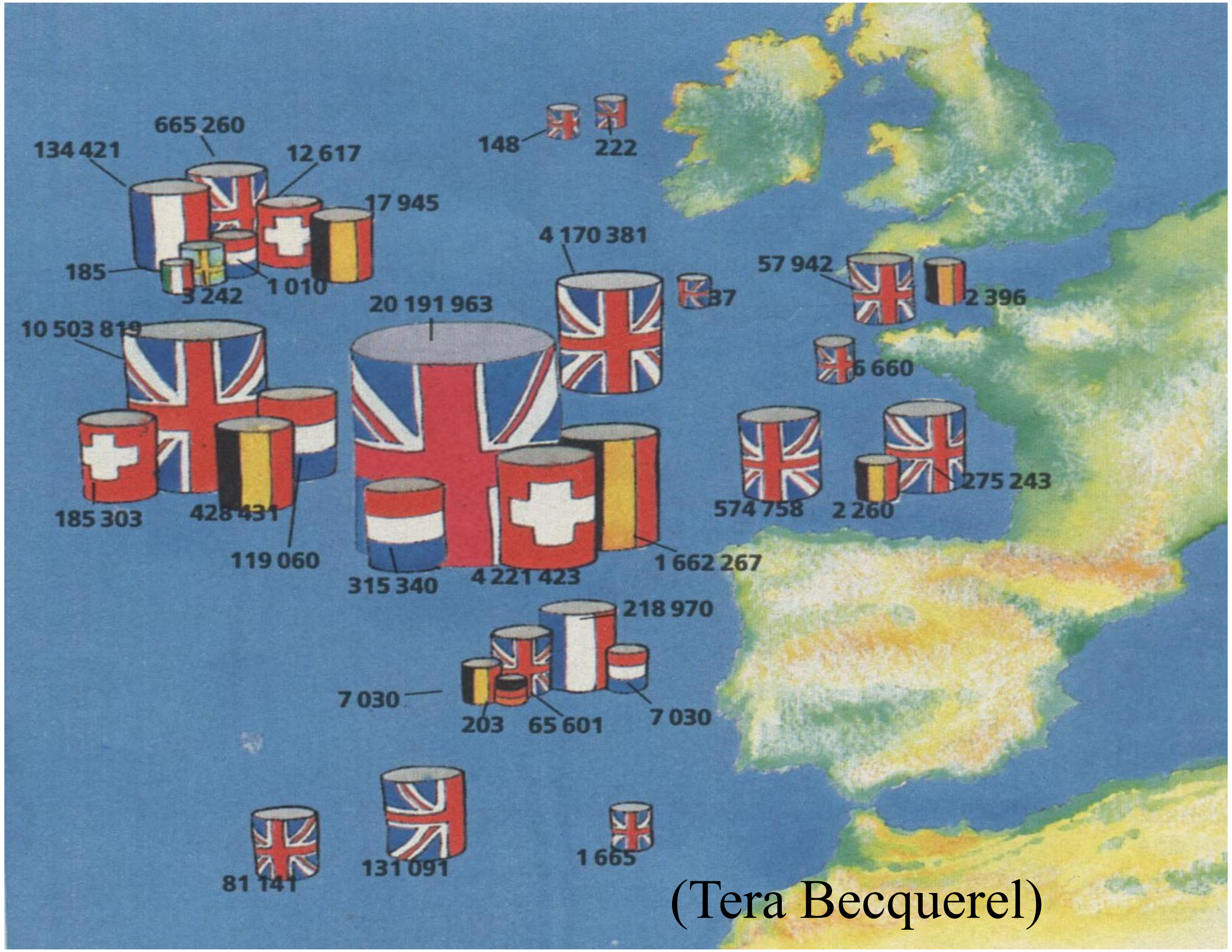



$^{137}$Cs input to the ocean: 40 PBq



# Radioactive waste dumped into the North East Atlantic

# (1946-1982)




Radiactive waste from nuclear industries:

Ra-226

H-3

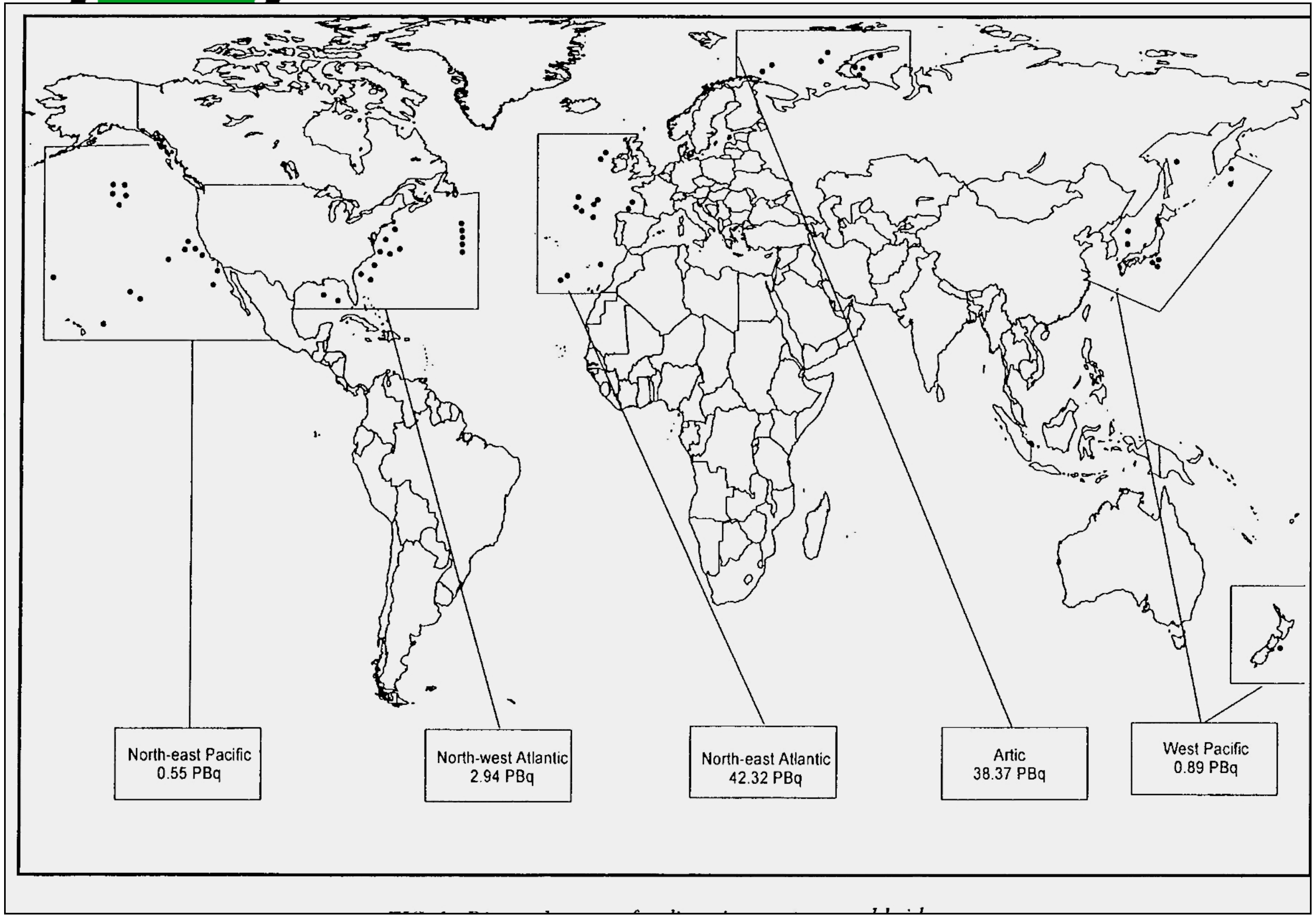
C-14

Pu-239,240

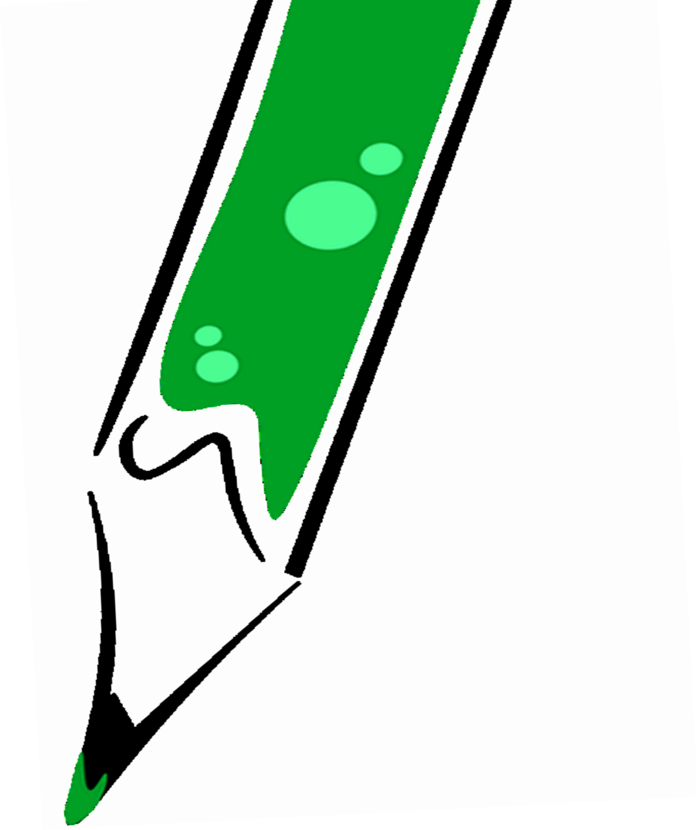
Sr-90

...

# Sites of immersion of radioactive waste in the ocean

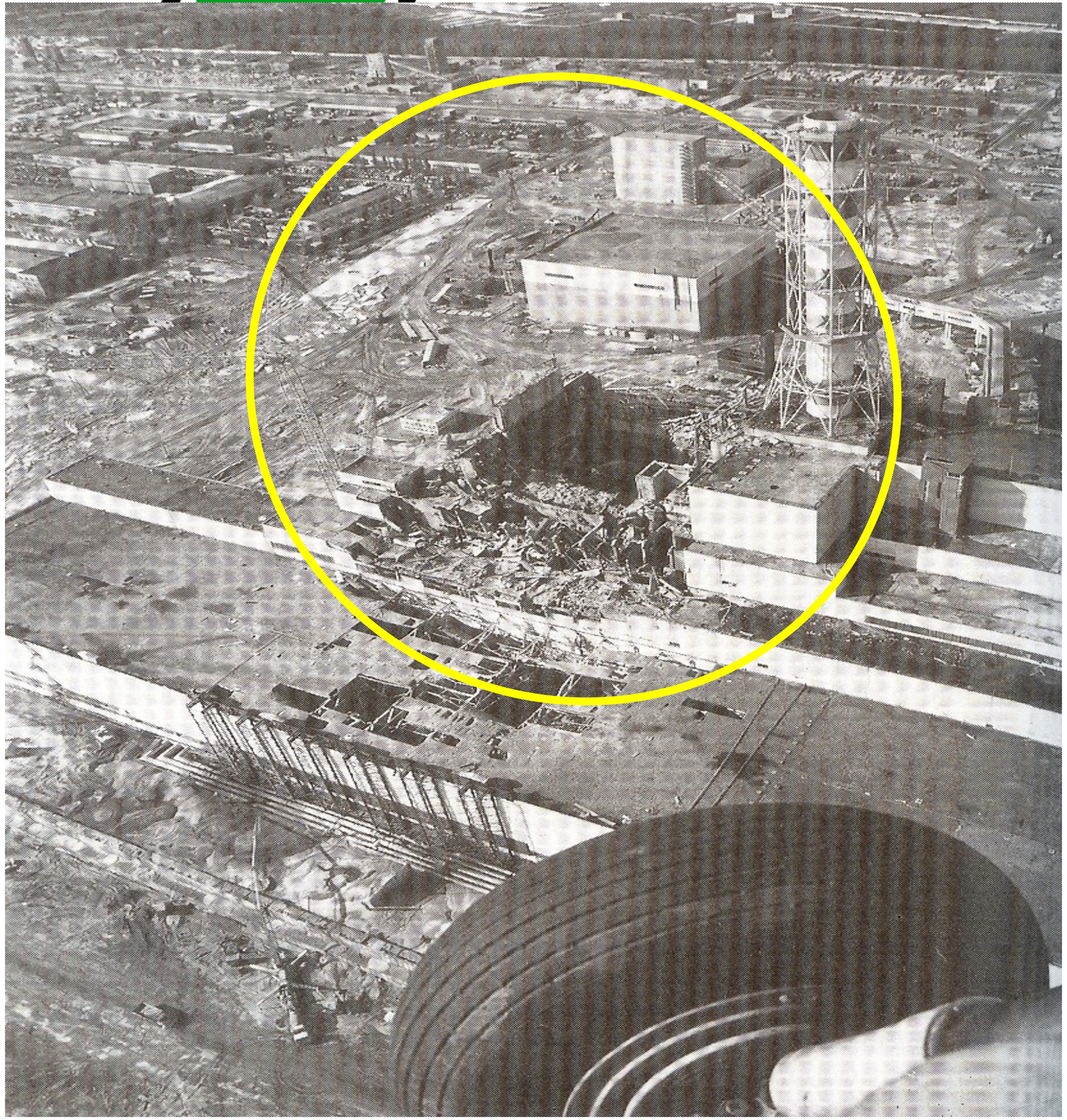



- Practice not acceptable today
- Legacy from past poor waste management policies
- Waste dumping into the sea is forbidden since 1982 (London Sea Dumping Convention)



# Nuclear accidents and cross-border contamination

# Nuclear accident at Chernobyl



26 April 1986

Ukraine

De Cort *et al.*,1998, EC, Luxembourg.

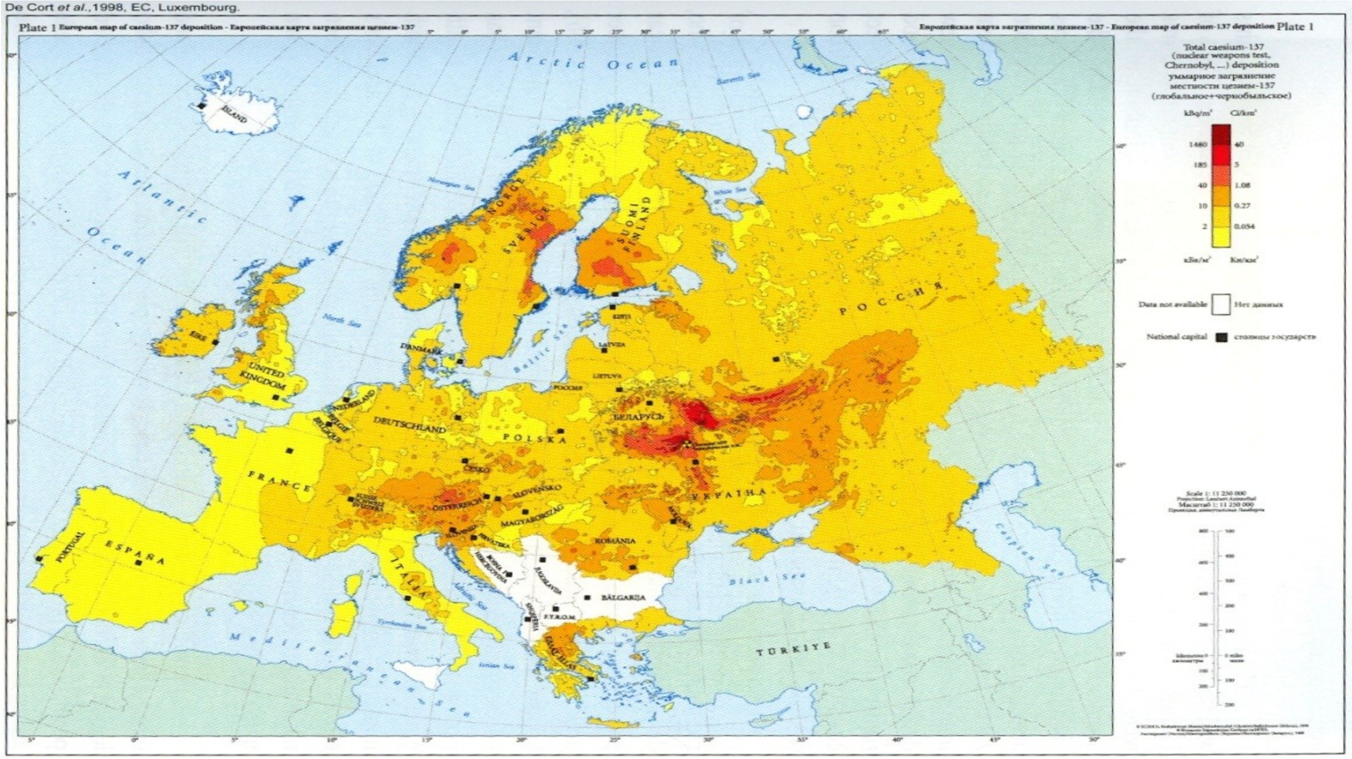
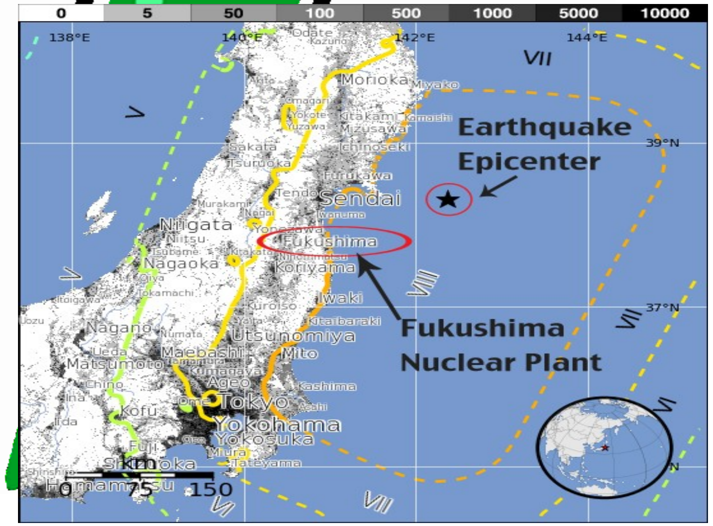



Figure 2 Map of Caesium-137 deposition following the accident.

# Nuclear accident at Fukushima

**Japan, March 11, 2011**
**The triple disaster: earthquake, tsunami, nuclear accident**

# Nuclear disaster



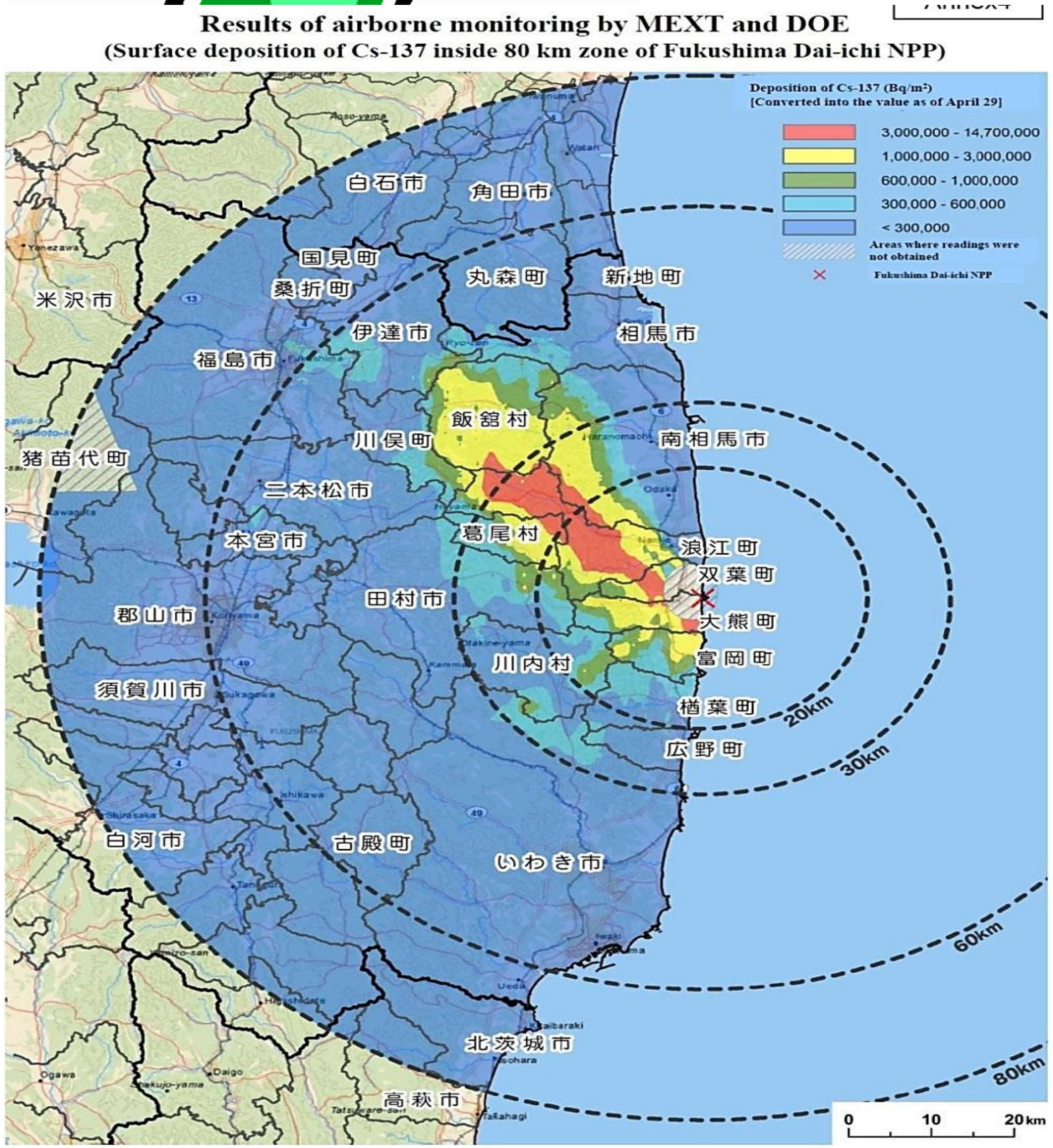

Fukushima Daiichi NPP:

- 6 units (BWR reactors)
- Units 1-3 were in operation; units 4-6 were stopped in maintenance)
- Tsunami flooded buildings and cut power. Units 1 to 3 left with battery power only.

Fukushima-Daiichi Nuclear Power Plant Information

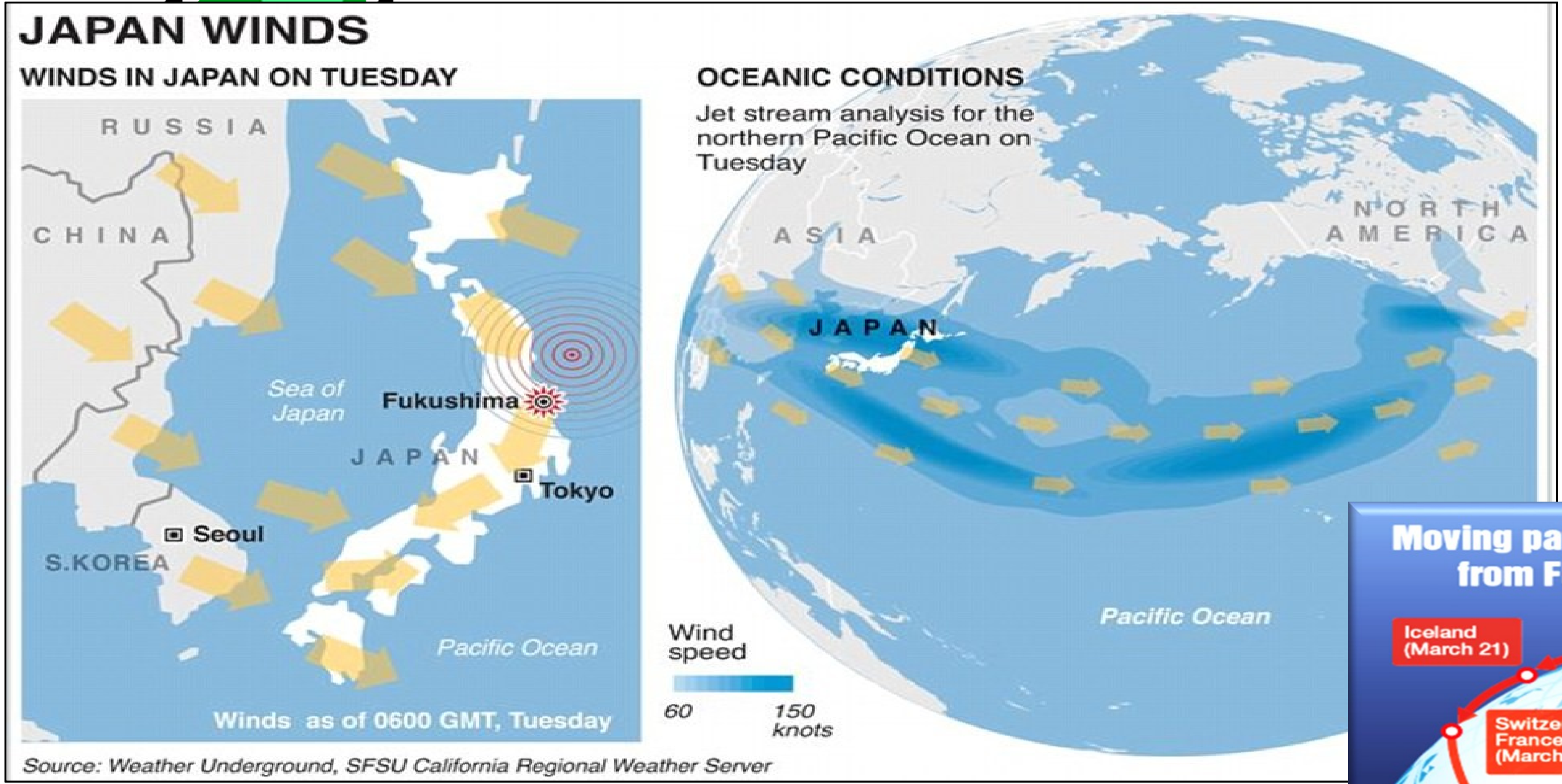

Source: Tokyo Electric Power Company

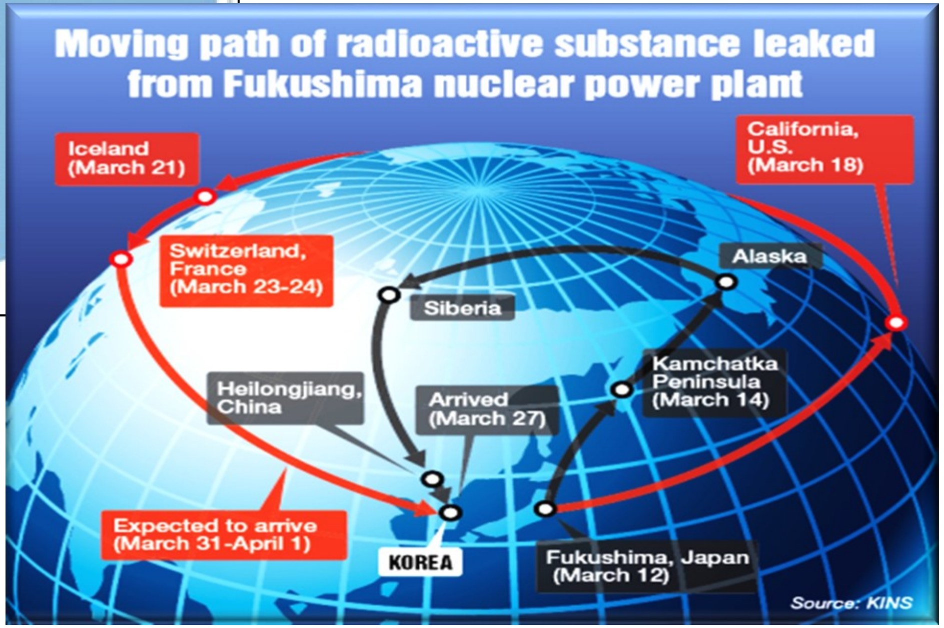
# Cesium-137 deposition




- 137Cs depositions
- Soil, houses and food contaminated
- People moved to other regions
- Discharge of large amounts of contaminated water into the sea

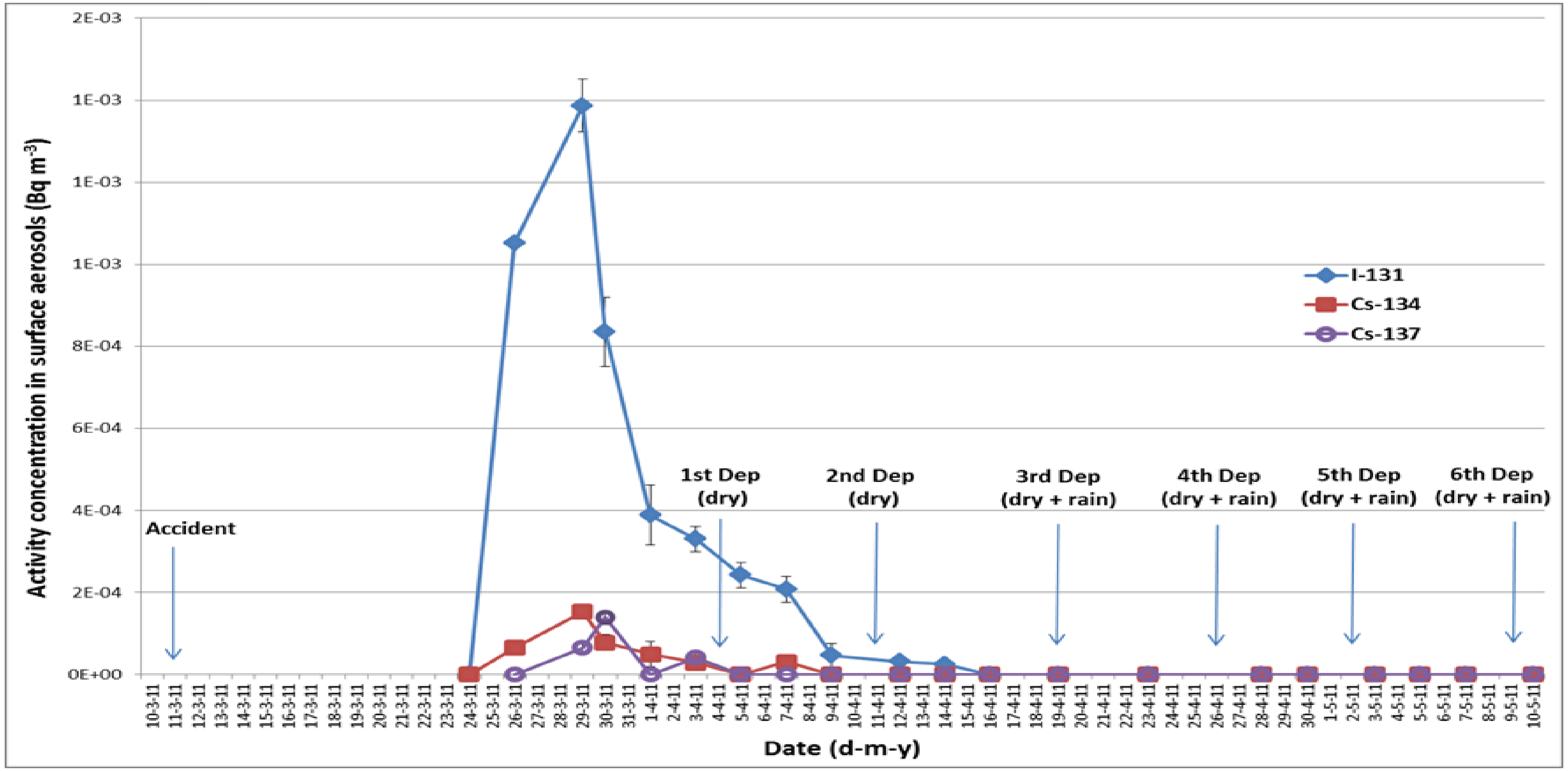
# Airborne contamination outside Japan




Radionuclides released were transported by the global atmospheric circulation

# Radionuclides measured at Lisbon




Radionuclides determined in air filters at Sacavém, Lisbon, following the Fukushima Daiichi nuclear accident. Arrows indicate the collection date of atmospheric deposition samples (Carvalho et al., J. Environ. Radioactivity 2012)

Environmental Science & Technology

ARTICLE

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# Tracking of Airborne Radionuclides from the Damaged Fukushima Dai-Ichi Nuclear Reactors by European Networks

O. Masson,[†,*] A. Baeza,[η] J. Bieringer,[⊥] K. Brudecki,[#] S. Bucci,[θ] M. Cappai,[θ] F.P. Carvalho,[≠] O. Connan,[§]

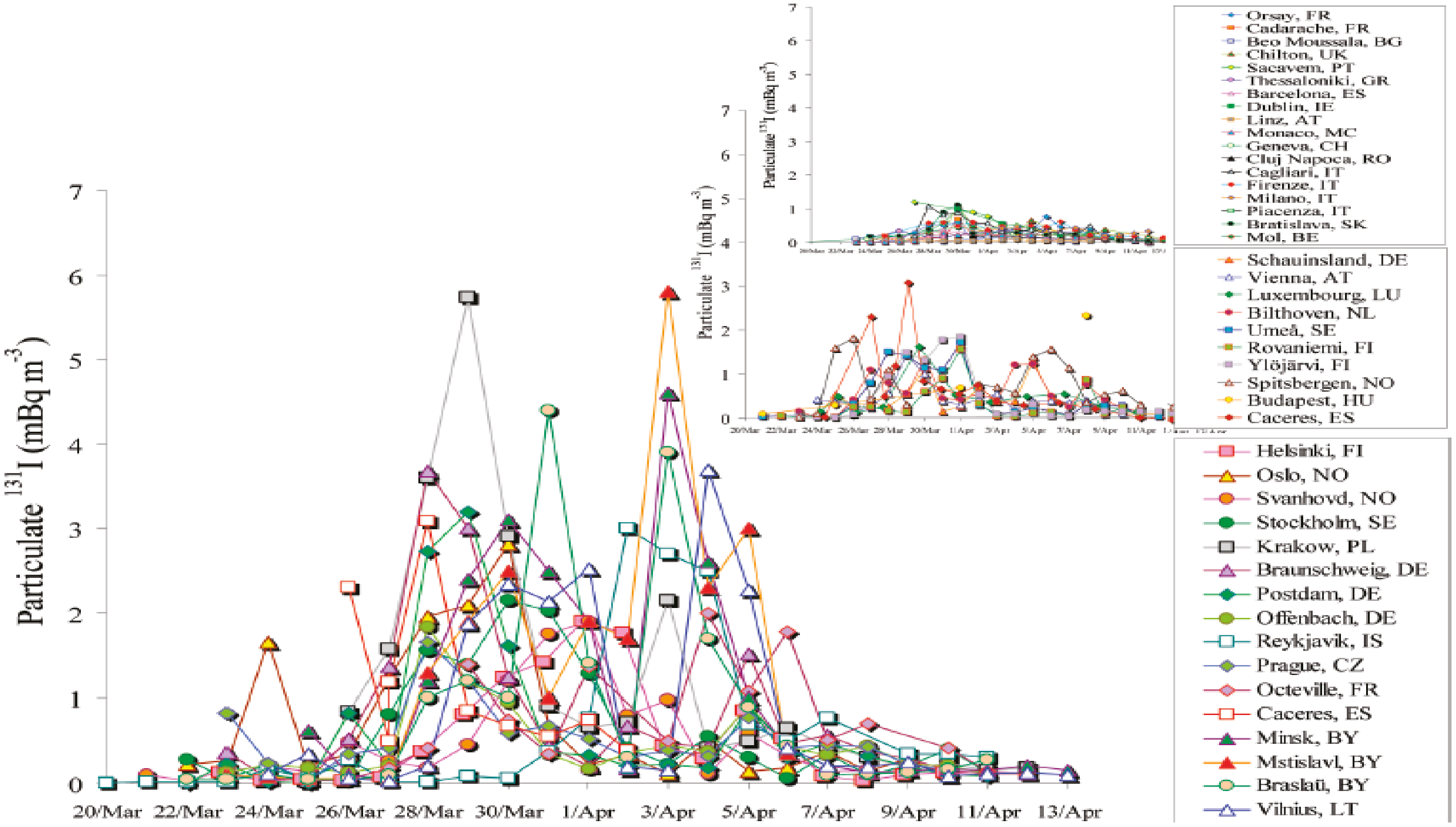
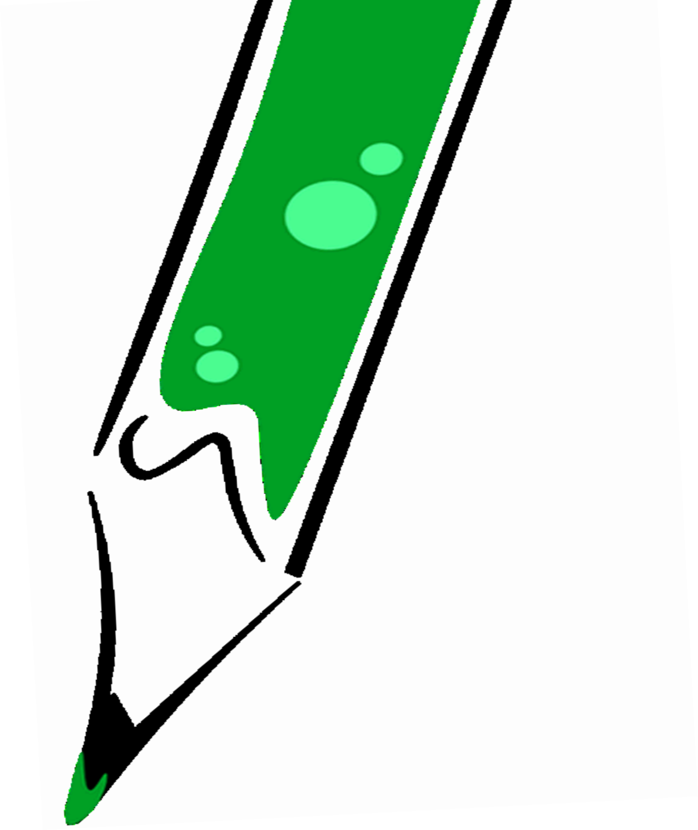


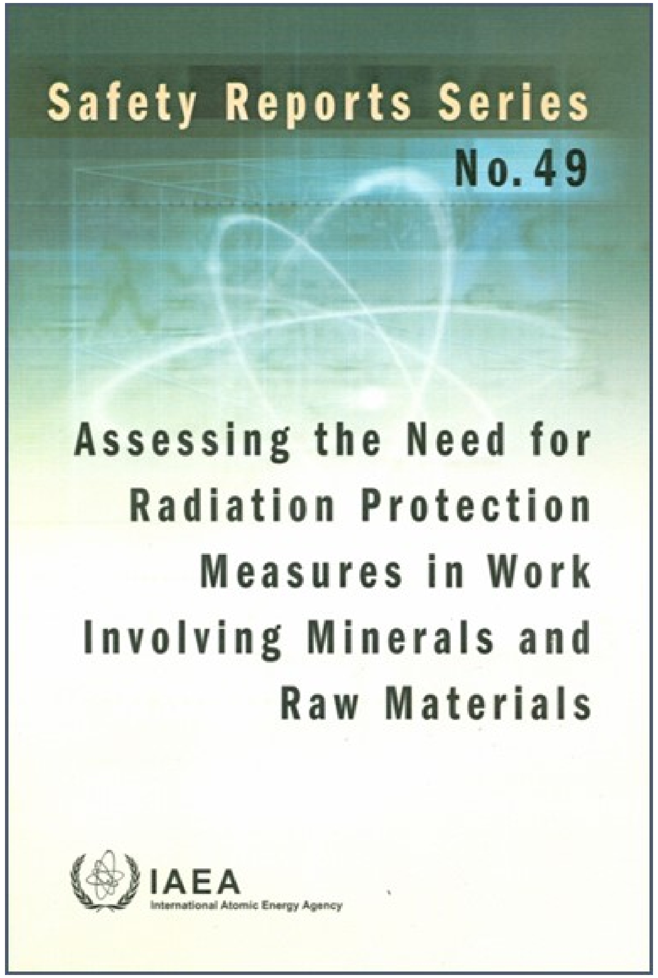

**Figure 1.** Time series of particulate $^{131}$I (mBq m$^{-3}$) in northern and central Europe (bottom), western and southern Europe (middle and top) due to the Fukushima releases.



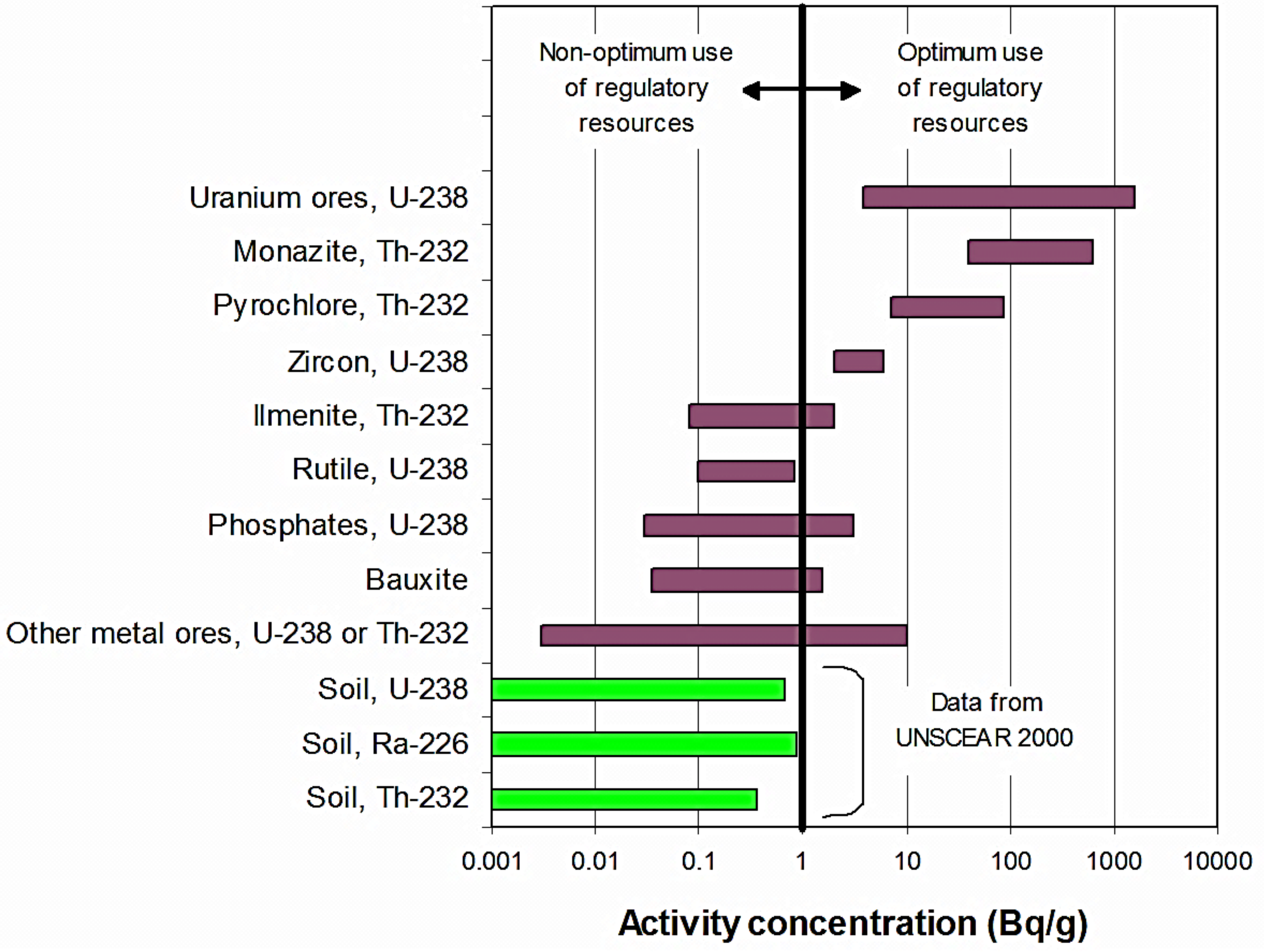
# Naturally-occuring radioactive materials (NORM) and industries

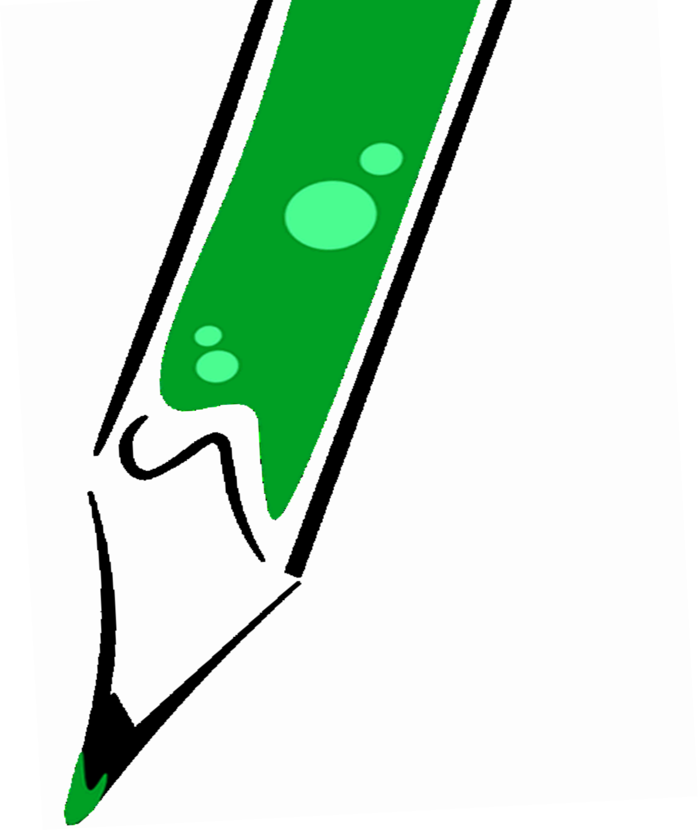
# Industries that process NORM

- Industries process raw materials that contain natural radionuclides
- Radionuclides may become strongly concentrated in products, wastes, or in the facilities
- Workers may be exposed to significant radiation doses
- Wastes may contain high levels of radionuclides and expose the public to radiation doses above safety limits.
- Therefore, also non-nuclear industries must be assessed to evaluate radiation risks



# Range of activity concentrations in soil, ores, and minerals





# Environmental monitoring for radiation protection of the population

# Environmental radioactivity monitoring

## Continuous

- Automatic measurements, by stand alone equipment
- Ambient dose rate
- Total alpha/beta counting
- Gamma spectrometry of aerosols

Advantages:

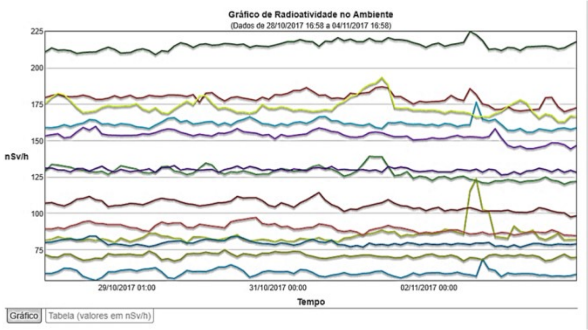
- Real time monitoring for alarm and emergency response
- International networks allow for synoptic observation

## Discontinuous

- Based on sample collection and laboratory analysis
- Analysis of water, foods, soils etc.
- Accurate results for activity concentrations

Advantages:

- Follow up of the status of the environment
- Verification of compliance by industries
- Data on produts support international trade




# CONCLUSIONS

- The occurrence of radionuclides of natural and artificial origin requires continuous/frequent monitoring of radioactivity in foods, drinking water, and in the environment.
- There are maximum limits for radioactivity in water and foods that must not be exceeded in order to protect public health.
- There are dose limits for exposures from all pathways and all radionuclides, for workers and for members of the public, that are legally enforced to ensure radiation safety.

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# Thank you for your kind attention!

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