MENV PRO

Co-funded by the Erasmus+ Programme of the European Union

Radioactivity in the diet

Fernando P. Carvalho

The Environmental Science Education for Sustainable Human Health

6 – 13 September 2021

UNIVERSITÀ DEGLI STUDI DELLA TUSCIA

GIRAF PM

NAS RA INTERNATIONAL SCIENTIFIC EDUCATIONAL CENTER

MARTIN-LUTHER-UNIVERSITÄT HALLE-WITTENBERG

UNIVERSITY OF GEORGIA

TÉCNICO LISBOA

GRENA GEORGIAN RESEARCH AND EDUCATIONAL NETWORKING ASSOCIATION

Co-funded by the Erasmus+ Programme of the European Union

Radioactivity in the diet and assessment of the effective dose to the members of the public

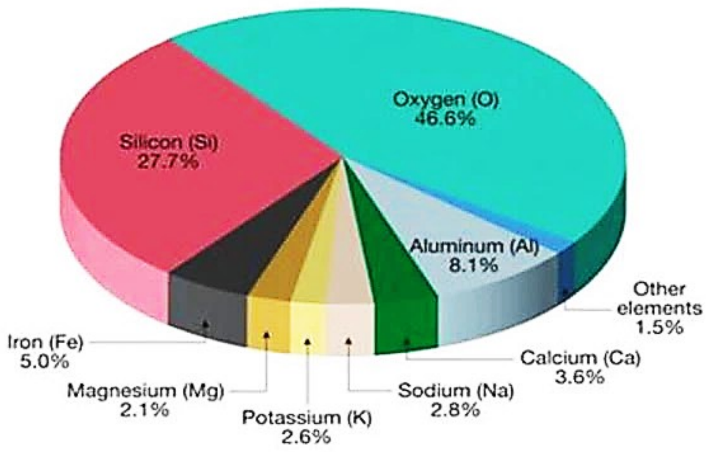
Fernando P. Carvalho
Laboratório de Protecção e Segurança radiológica
Instituto Superior Técnico/Campus Tecnológico Nuclear
Universidade de Lisboa
Estrada Nacional 10, km 139,7
2695-066 Bobadela LRS
Portugal
E-mail: carvalho@ctn.tecnico.ulisboa.pt

Outline

- Radionuclides in the diet: which ones and why.
- Monitoring the food chain
- Total Effective Dose to humans
- Advantages of an Environmental Monitoring Programm
- Conclusions

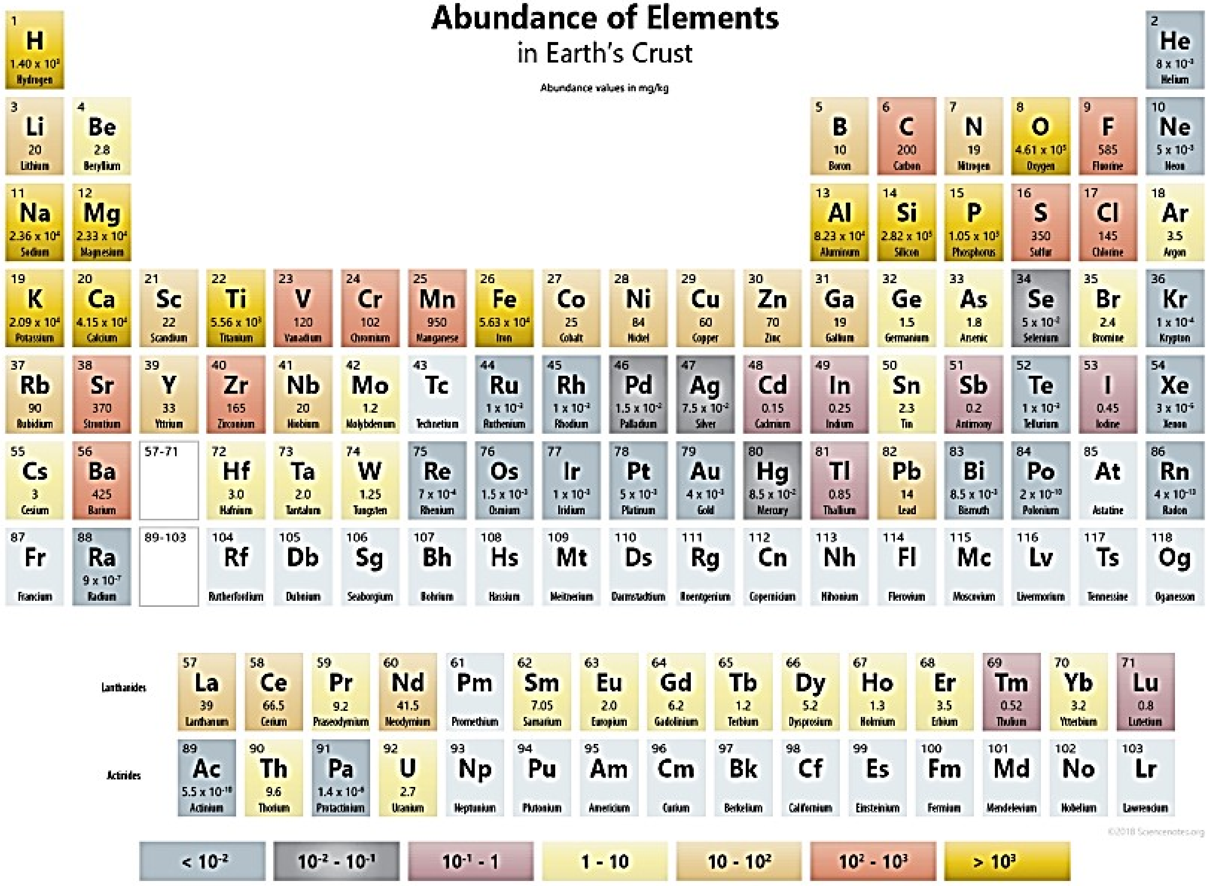
Radionuclides in the diet: which ones and why

Radionuclides are present in the Earth crust

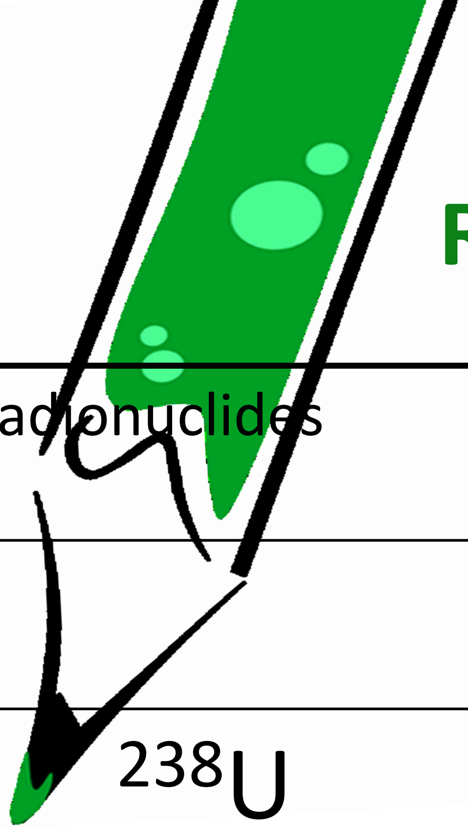


Radionuclides both of natural origin and of artificial origin are widely present in our environment

Ingestion of atoms of these radionuclides with foods and water is unavoidable.



ABUNDANCE OF SOME RADIONUCLIDES IN THE ENVIRONMENT



Radionuclides	Earth crust		Sea water		Atmosphere	
	mg/kg	**Bq/kg**	mg/kg	**Bq/kg**	mg/L	Bq/L
^{238}U	3	**33**	$3x10^{-3}$	**$3.7x10^{-2}$**	-	-
^{226}Ra	$1x10^{-6}$	**33**	$1x10^{-10}$	**$3.7x10^{-3}$**	-	-
^{210}Po	$2x10^{-10}$	**33**	$7x10^{-15}$	**$1.1x10^{-3}$**	-	-

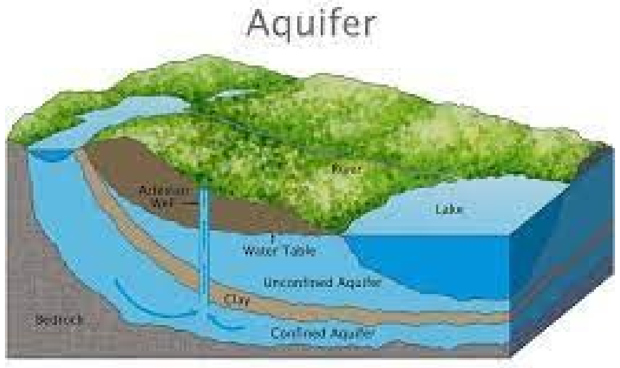
Why to assess radioactivity in the diet (1)

Naturally occurring radionuclides:

They are part of our natural environment. Is their ingestion ok ?

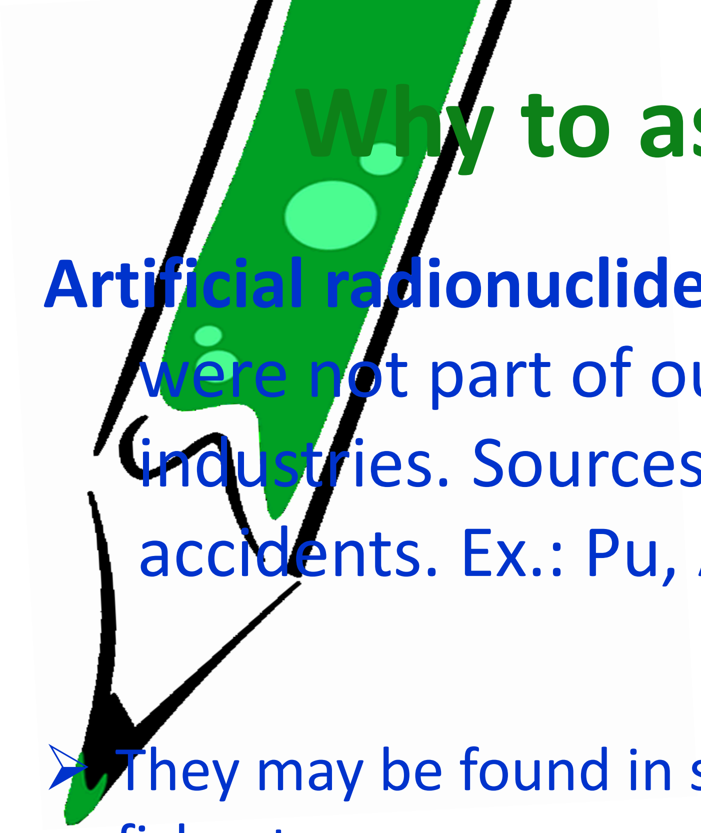
No! Too much of 226 Ra, 210Po, 210Pb or Rn (radon) can be harmful.

- **Drinking water (groundwater) contain radionuclides in high concentrations. There are recommended limits for radionuclides in drinking water.**



- **Some foods (sea foods) may contain high concentrations of natural radionuclides, such as 210Po. Not regulated.**

- **Some industrial products may contain enhanced conc. of natural radionuclides. Ex fosforic acid added to animal feeds for cattle and poultry.**



Why to assess radioactivity in the diet (2)

Artificial radionuclides

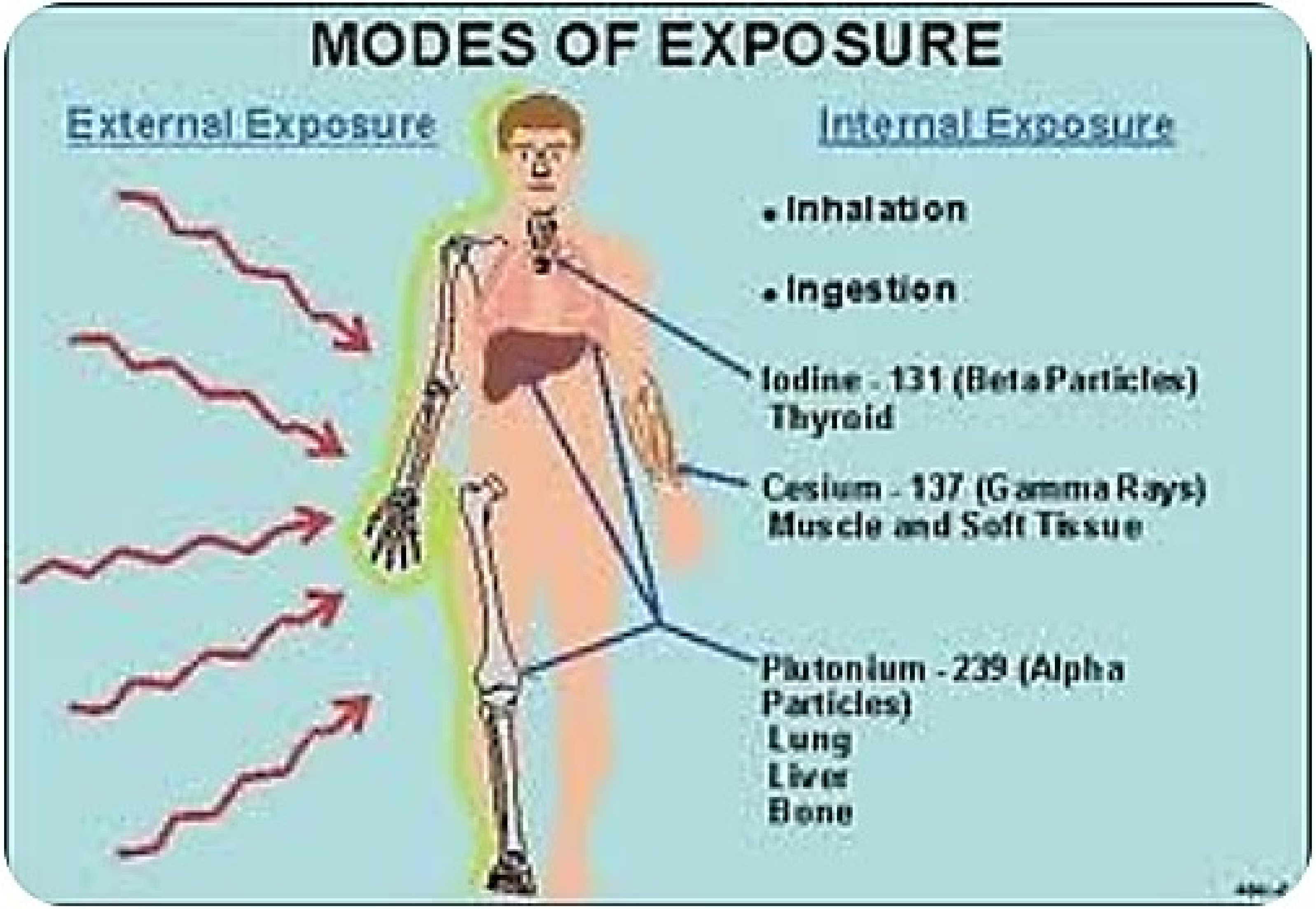
were not part of our natural environment and were introduced by nuclear industries. Sources: weapon tests, nuclear fuel reprocessing, nuclear accidents. Ex.: Pu, Am, I, Cs, Sr.

- They may be found in soils, in aerosols and thus in the vegetables, milk, beef, water fish, etc.
- The most dangerous are the alpha emmitters (Pu, Am), although less absorbed through the gut.

  Iodine (131I) is easily concentrated in thyroid gland through ingestion and inhalation,

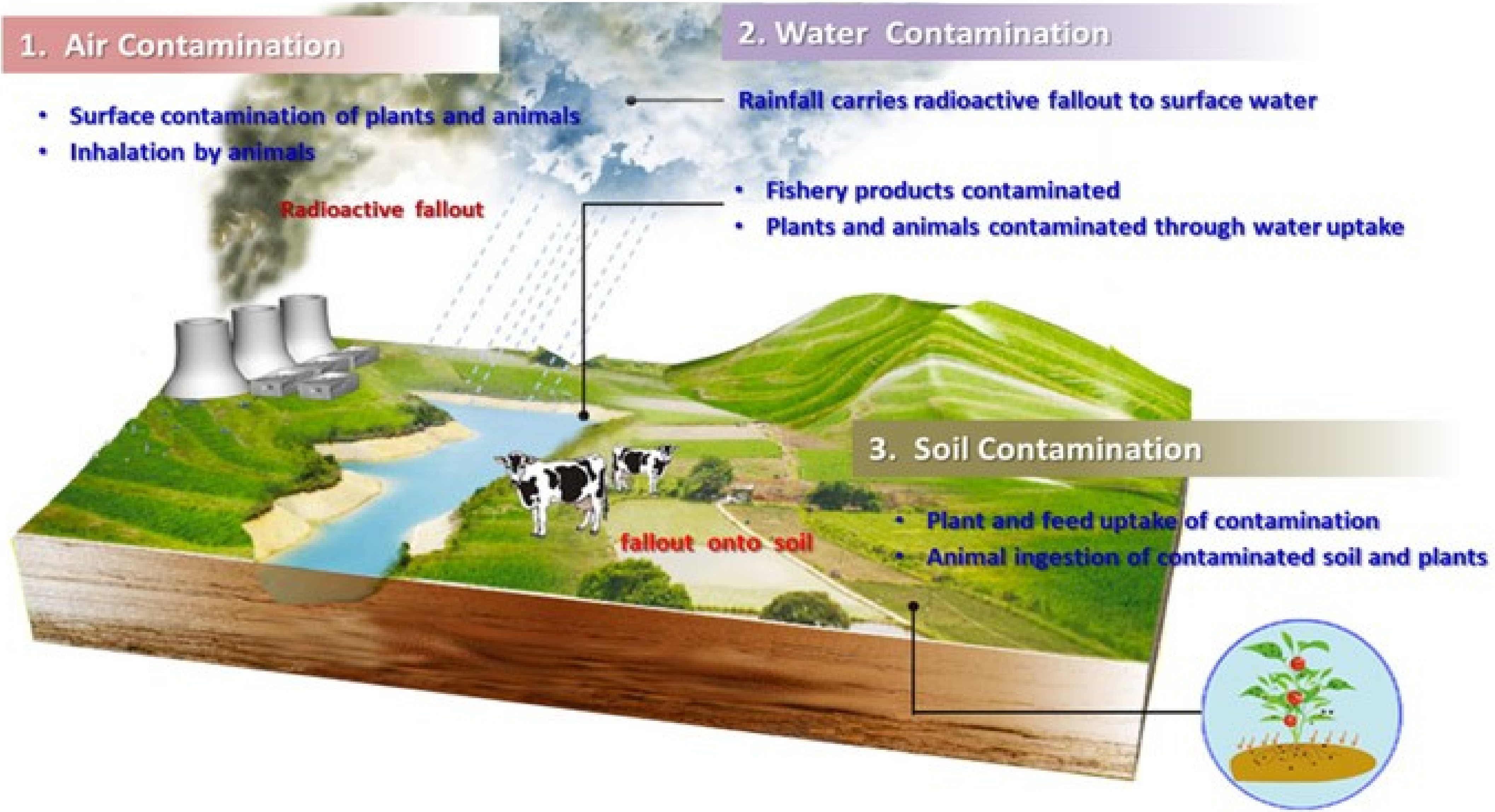
  90Sr is absorbed through ingestion and concentrated in the bone tissue

EXPOSURE PATHWAYS TO RADIONUCLIDES

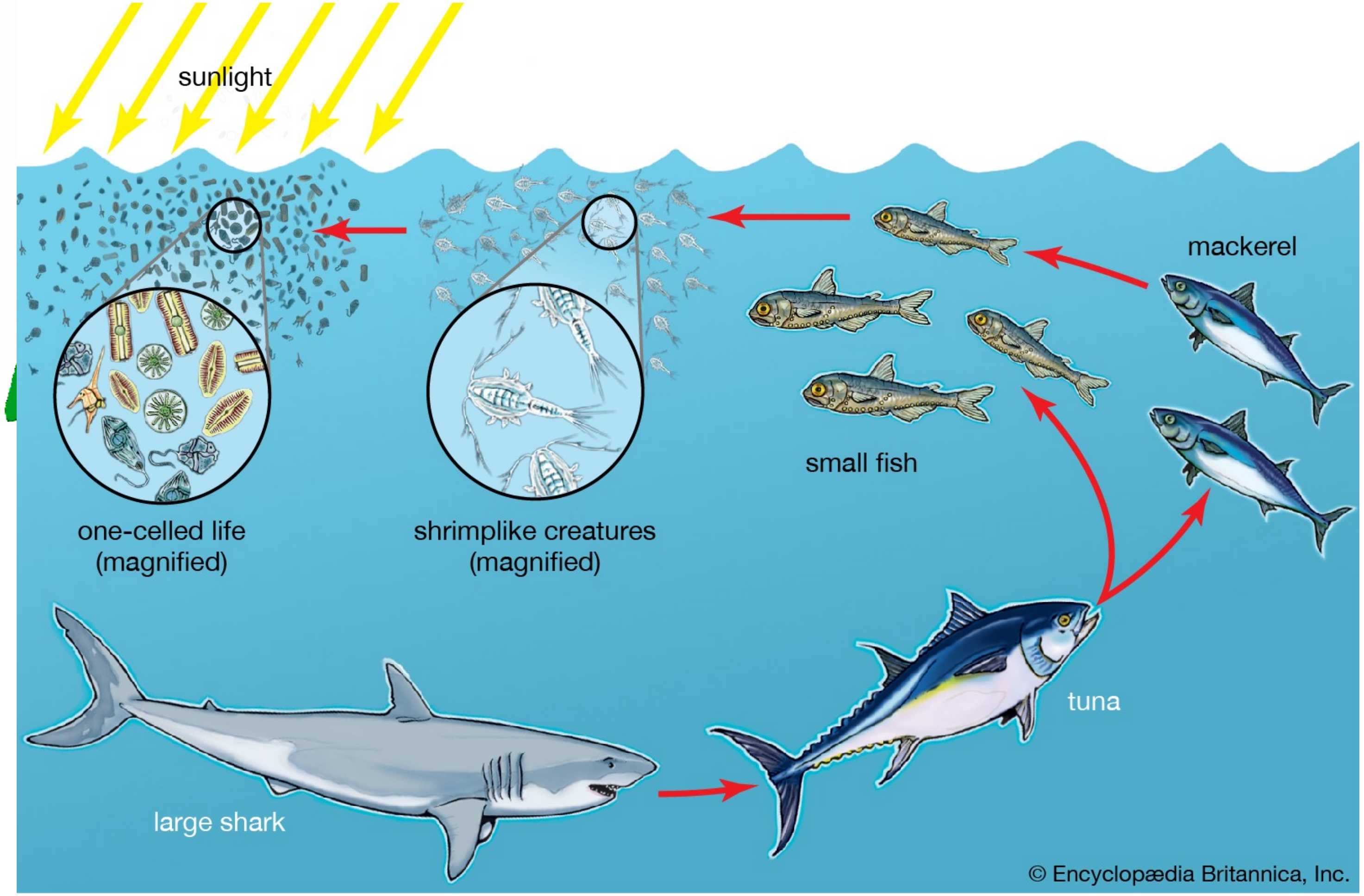


Monitoring the food chain

Pathways of radioactive contamination to agricultural products

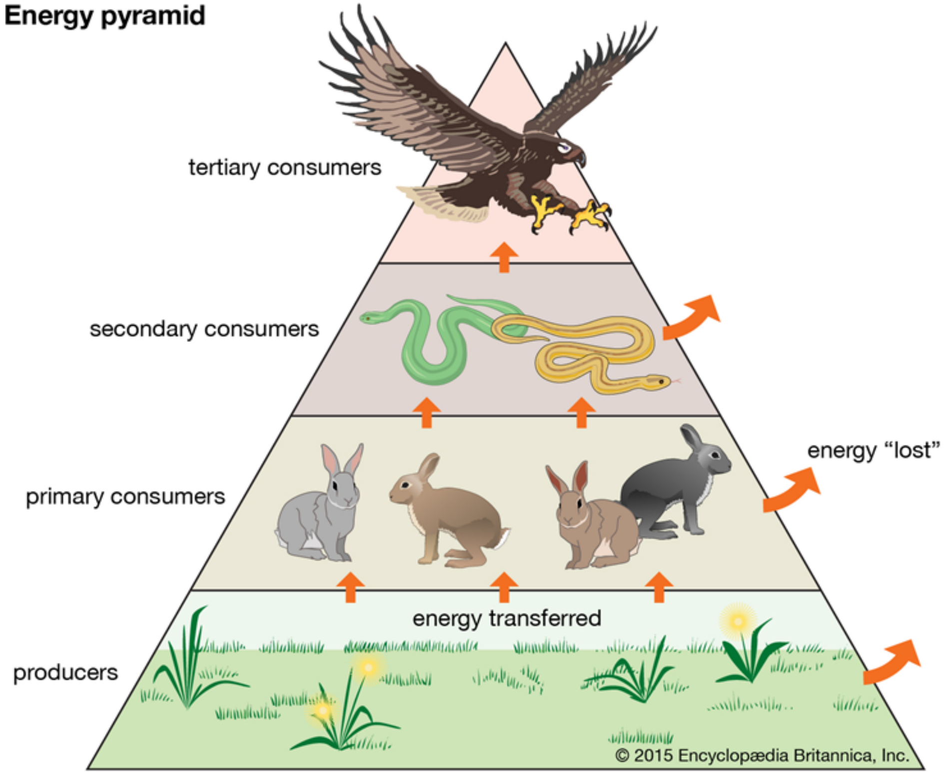


Transfer of radionuclides in marine food chains

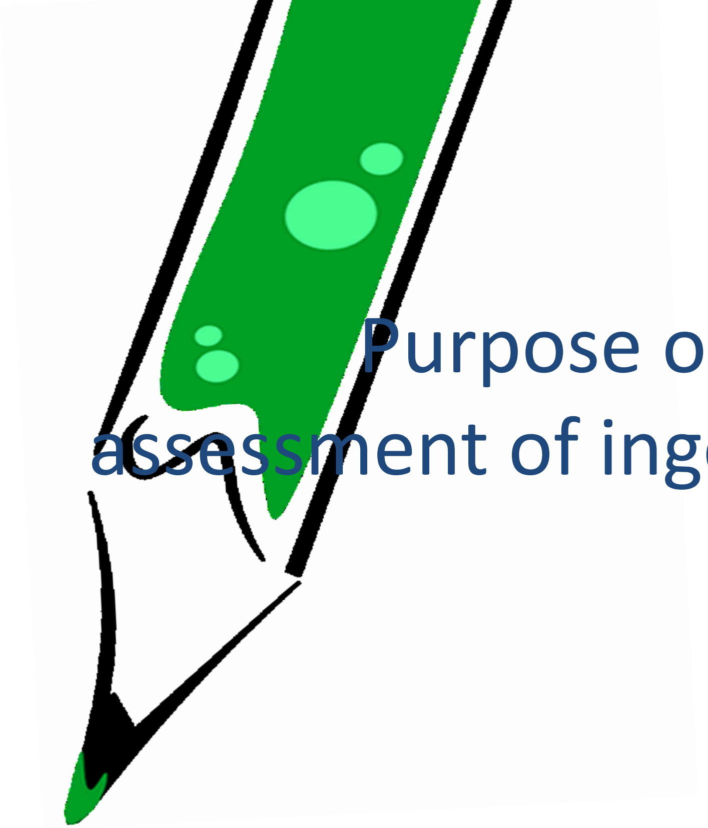


Radionuclides (natural and artificial) are taken from solution by plankton, accumulated, and transferred along the food chain

Transfer of radionuclides in terrestrial food chains



Both natural and artificial radionuclides are transferred in food chains



Purpose of radioactivity monitoring of food chain:
assessment of ingestion of radionuclides by humans with the diet

Monitoring the food chain

Done in two ways:

- **Market basket survey**: selected foods are sampled and analyzed (ex: beef and cheese from several regions) (Advantage: helps to identify single products that might be contaminated; also useful to certify non contamination and facilitate export)

- **Complete (actual) meals**: Represents more accurately what is ingested (effects of the cooking)

Water for human consumption

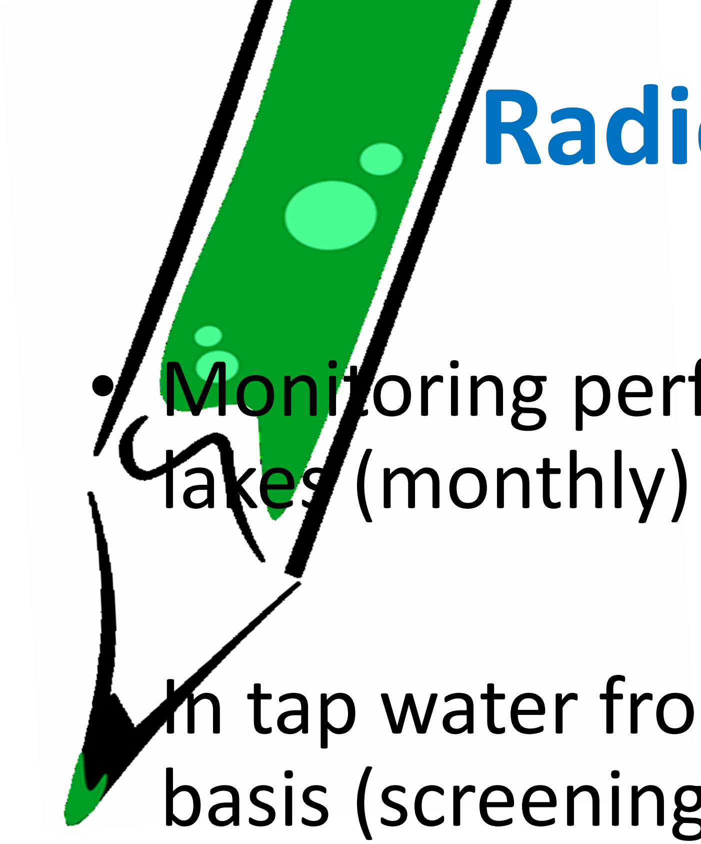
Preparation and measurement of drinking water samples for the determination of radionuclide concentrations and total alpha and beta activity.

Activity concentration values A ± u (k = 2) (Bq L^{-1}), 137Cs, 90Sr, 3H, total alpha and total beta activity in drinking water of Lisbon (public water supply)

Data de colheita	^{137}Cs	^{90}Sr	^{3}H	Alfa Total	Beta Total
Janeiro	$<2,59\times10^{-3}$ (a)	$(2,00\pm0,53)\times10^{-3}$	<0,41 (c)	<0,071 (d)	<0,210 (e)
Fevereiro	$<3,60\times10^{-3}$ (a)	$(1,28\pm0,51)\times10^{-3}$	<0,40 (c)	<0,037 (d)	<0,105 (e)
Março	$<2,58\times10^{-3}$ (a)	$(1,85\pm0,72)\times10^{-3}$	<0,44 (c)	<0,045 (d)	<0,158 (e)
Abril	$<2,98\times10^{-3}$ (a)	$<1,59\times10^{-3}$ (b)	<0,40 (c)	<0,053 (d)	<0,188 (e)
Maio	$<2,17\times10^{-3}$ (a)	$(1,33\pm0,64)\times10^{-3}$	<0,45 (c)	<0,044 (d)	<0,154 (e)
Junho	$<4,00\times10^{-3}$ (a)	$<2,18\times10^{-3}$ (b)*	$0,54\pm0,20$	<0,050 (d)	<0,173 (e)
Julho	$<4,00\times10^{-3}$ (a)	$<3,16\times10^{-3}$ (b)*	$0,88\pm0,30$	<0,035 (d)	<0,117 (e)
Agosto	$<4,00\times10^{-3}$ (a)	$(2,76\pm0,97)\times10^{-3}$	<0,44 (c)	<0,040 (d)	<0,129 (e)
Setembro	$<3,39\times10^{-3}$ (a)	$(2,03\pm0,70)\times10^{-3}$	$1,32\pm0,32$	<0,047 (d)	<0,153 (e)
Outubro	$<3,56\times10^{-3}$ (a)	$(2,2\pm1,1)\times10^{-3}$	$2,29\pm0,39$	<0,046 (d)	<0,155 (e)
Novembro	$<3,45\times10^{-3}$ (a)	$(2,15\pm0,65)\times10^{-3}$	$2,40\pm0,37$	<0,035 (d)	<0,111 (e)
Dezembro	$<4,62\times10^{-3}$ (a)	$(1,94\pm0,86)\times10^{-3}$	$0,77\pm0,29$	<0,030 (d)	<0,096 (e)
Média ± σ (n=12)	$<3,41\times10^{-3}$	$<2,04\times10^{-3}$	<0,90	<0,044	<0,146

Atividade mínima detetável em ^{137}Cs (a), ^{90}Sr (b), ^{3}H (c), atividade alfa total (d) e atividade beta total (e).
*Devido a uma avaria do equipamento de medição, estas amostras foram medidas algum tempo após a sua preparação. Como o ^{90}Sr é determinado a partir do seu descendente ^{90}Y, o qual apresenta um período de semi-vida relativamente curto (64 h), a não medição das amostras logo após a sua preparação pode ter influenciado os valores das concentrações de atividade reportados devido ao decréscimo rápido da atividade em ^{90}Y.

Radioactivity in drinking water



- Monitoring performed in main water supply sources-artificial lakes (monthly)

- In tap water from Lisbon, and from other cities on a rotation basis (screening)

- NOTE: Water companies must provide detailed analysis of tap water quality to Water Authority and render them public (periodically)

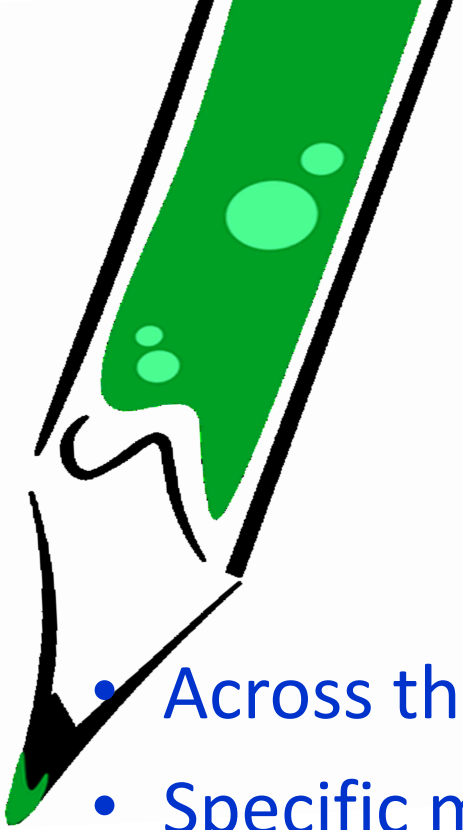
Radioactivity in the food chain

Preparation of food samples and measurement by gamma spectrometry

Activity concentration values A ± u(k = 2) (Bq kg^{-1} fresh weight), radionuclides 137Cs, 131I, 90Sr and 40K in the food chain

Entidade responsável pela colheita	Data de colheita	Local de colheita	Produto	^{137}Cs	^{131}I	^{90}Sr	^{40}K
ASAE (Região Alentejo)	Janeiro	Portalegre	Alface	<0,10 (a)	<0,16 (b)	-	127,2 ±9,5
			Batata	<0,11 (a)	<0,09 (b)	-	132,1±9,6
			Maçã	<0,12 (a)	<0,11 (b)	-	32,4±3,4
			Carne (Bovino)	<0,11 (a)	<0,38 (b)	<0,044 (c)	102,9±8,0
ASAE (Região Centro)	Janeiro	Leiria	Couve	<0,13 (a)	<0,20 (b)	<0,020 (c)	84,6±7,1
		Aveiro	Batata	<0,13 (a)	<0,19 (b)	-	180±13
		Leiria	Laranja	<0,10 (a)	<0,14 (b)	-	41,4±4,0
		Coimbra	Carne (Bovino)	<0,10 (a)	<0,23 (b)	<0,047 (c)	96,9±7,2
ASAE (Região Norte)	Fevereiro	Viana do Castelo	Couve	<0,13 (a)	<0,22 (b)	<0,031 (c)	92,0±7,5
		Aveiro	Batata	<0,13 (a)	<0,20 (b)	-	157±12
			Laranja	<0,09 (a)	<0,15 (b)	-	46,5±3,9
		Viana do Castelo	Carne (Bovino)	<0,13 (a)	<0,20 (b)	<0,033 (c)	103,0±8,0
ASAE (Região Algarve)	Março	Faro	Couve	<0,20 (a)	<0,21 (b)	<0,028 (c)	63,6±5,2
			Batata	<0,10 (a)	<0,21 (b)	-	145±11
			Laranja	<0,11 (a)	<0,19 (b)	-	55,2±4,9
			Carne (Bovino)	<0,10 (a)	<0,21 (b)	<0,055 (c)	107,7±8,0
ASAE (Região Lisboa e Vale de Tejo)	Abril	Lisboa	Couve	<0,10 (a)	<0,29 (b)	0,045±0,024	94,0±7,3
			Cebola	<0,12 (a)	<0,02 (b)	-	40,7±4,0
		Leiria	Maçã	<0,09 (a)	<0,10 (b)	-	30,7±2,9
		Setúbal	Carne (Suíno)	<0,12 (a)	<0,33 (b)	<0,031 (c)	125,3±9,6
Inspeção Regional das Atividades Económicas dos Açores)	Abril	Angra Heroísmo	Alface	<0,14 (a)	<0,19 (b)	-	120,0±8,9
			Batata	<0,12 (a)	<0,10 (b)	-	105,0±7,9
			Laranja	0,30±0,10	<0,14 (b)	-	45,1±4,3
			Carne (Bovino)	0,84±0,12	<0,15 (b)	<0,066 (c)	95,9±7,2
ASAE (Região Centro)	Maio	Aveiro	Couve	<0,14 (a)	<0,26 (b)	<0,044 (c)	76,6±6,6
		Coimbra	Batata	<0,14 (a)	<0,11 (b)	-	95,7±7,7
		Aveiro	Laranja	<0,09 (a)	<0,10 (b)	-	57,5±4,7
		Leiria	Carne (Bovino)	<0,12 (a)	<0,18 (b)	0,026±0,012	105,3±8,2
Direção Regional de Agricultura da Região Autónoma da Madeira	Maio	Santana	Couve	<0,10 (a)	<0,20 (b)	0,059±0,019	101,5±7,7
			Batata	<0,12 (a)	<0,19 (b)	-	161±12
			Kiwi	<0,12 (a)	<0,11 (b)	-	68,6±5,8
		Ribeira Brava	Carne (Bovino)	<0,08 (a)	<0,22 (b)	<0,072 (c)	95,6±7,1
ASAE (Região Alentejo)	Junho	Évora	Alface	<0,10 (a)	<0,21 (b)	-	56,9±4,8
		Beja	Cebola	<0,07 (a)	<0,13 (b)	-	40,7±3,5
		Évora	Meloa	<0,13 (a)	<0,44 (b)	-	83,4±6,8
		S. Marcos Serra	Carne (Bovino)	<0,11 (a)	<0,35 (b)	<0,035 (c)	117,3±8,9

Atividade mínima detetável em ^{137}Cs (a), ^{131}I (b) e ^{90}Sr (c).

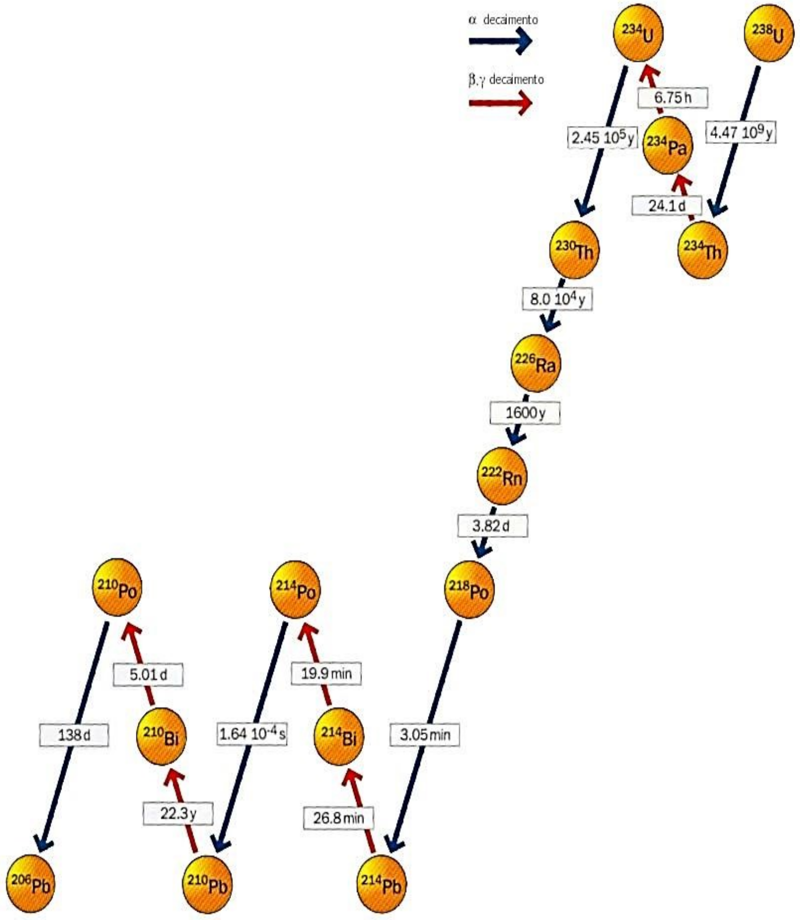


Where to collect samples?

- Across the country to assess the exposure of general population
- Specific monitoring programmes may be needed in areas around nuclear facilities and uranium mines

Uranium mines region

U facilities and waste piles



All radionuclides of uranium series are present

Nuclear facilities

Liquid and gas releases
May affect the neighbourhood and far regions

Nuclear power plants in Europe

Radionuclides of interest

The identification of "radionuclides of interest"

Examples:

- **Uranium mining and milling**

  Uranium chain: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po

- **Nuclear power plant**

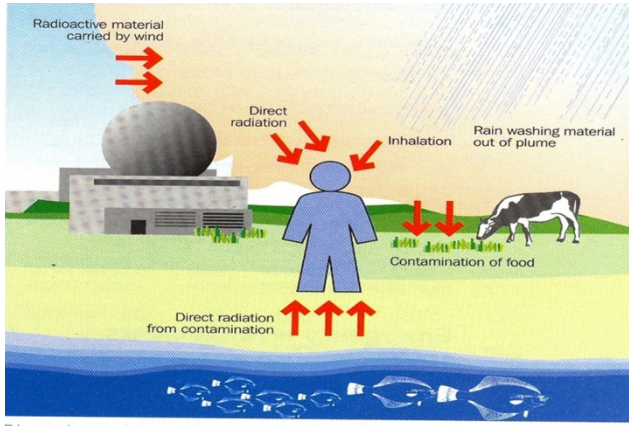
  Fission products: 137Cs, 140Ba, 90Sr, …

  Activation products: 60Co, 54Mn, 110mAg,…

  Tritium 3H

- **NORM industries (oil, gas, phosphate, …)**

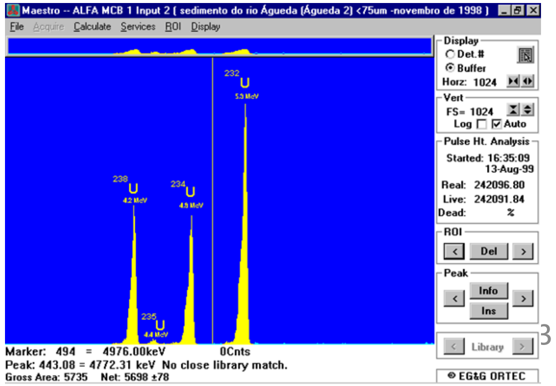
  Naturals: 210Po, 226Ra, 210Pb…



Dispersion and deposition from a radioactive plume

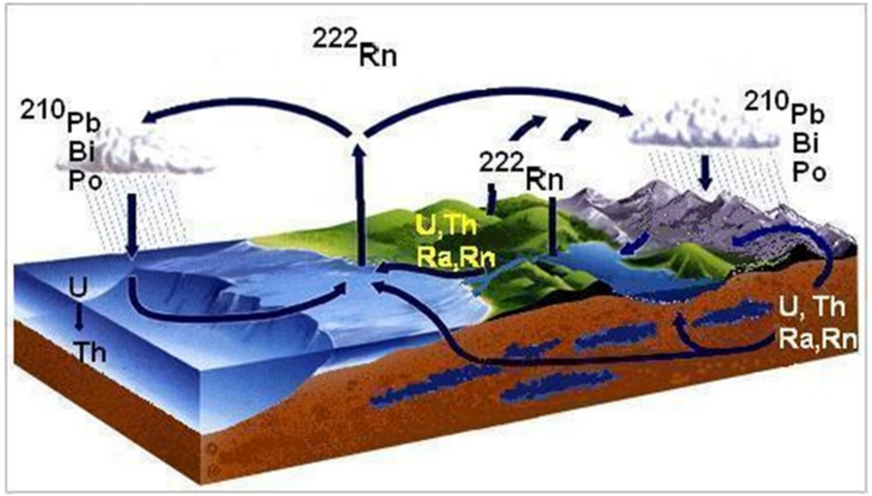
Analytical techniques

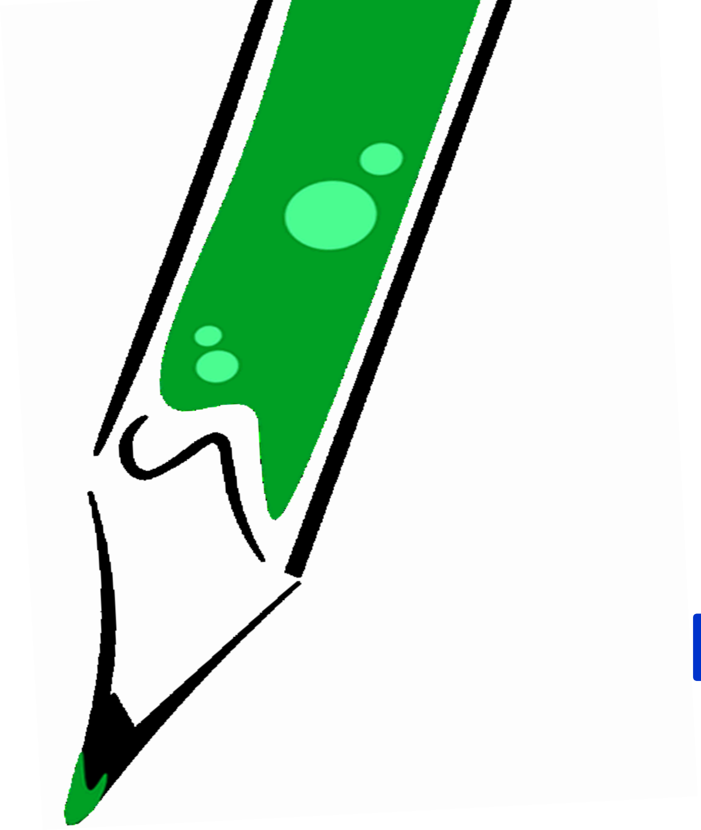
- Total alpha/total beta counting (Gas proportional counter)
- Total alpha/total beta counting (Liquid scintillation counting)
- Alpha spectrometry (Si detectors)
- Gamma spectrometry (HpGe detectors)



The importance of a baseline study

- **Radiation baseline study**
  - Knowing the current level of radiation exposure
    - External gamma radiation /ambient dose
    - Inhalation: gas, dust
    - Ingestion: water, food



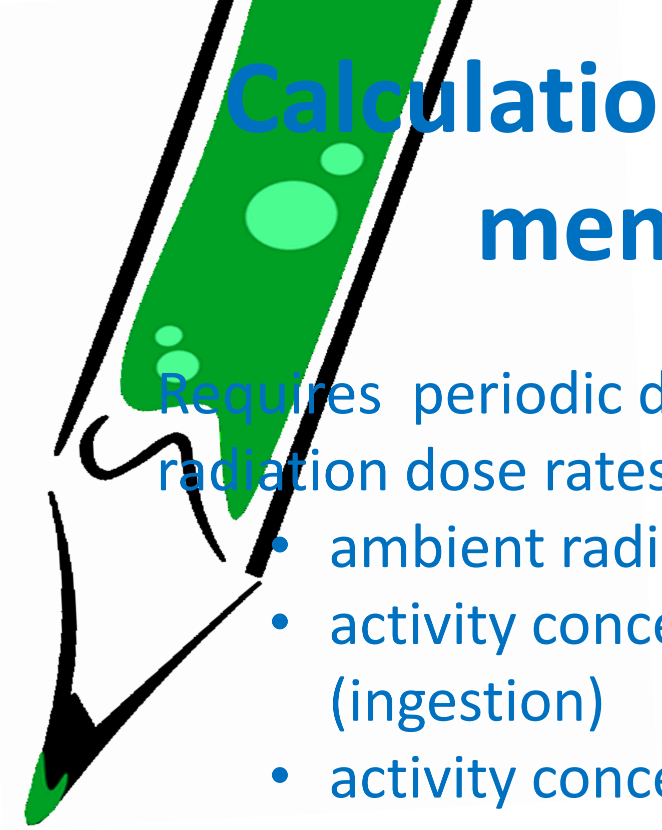


Effective dose to humans

Aim for the determination of radionuclides in the diet:

- assessment of the Effective Dose to the average member of the public
- check compliance with radiation dose limits
- ensure radiation protection of the nationwide population

Calculation of Effective Dose to the average member of the public nationwide

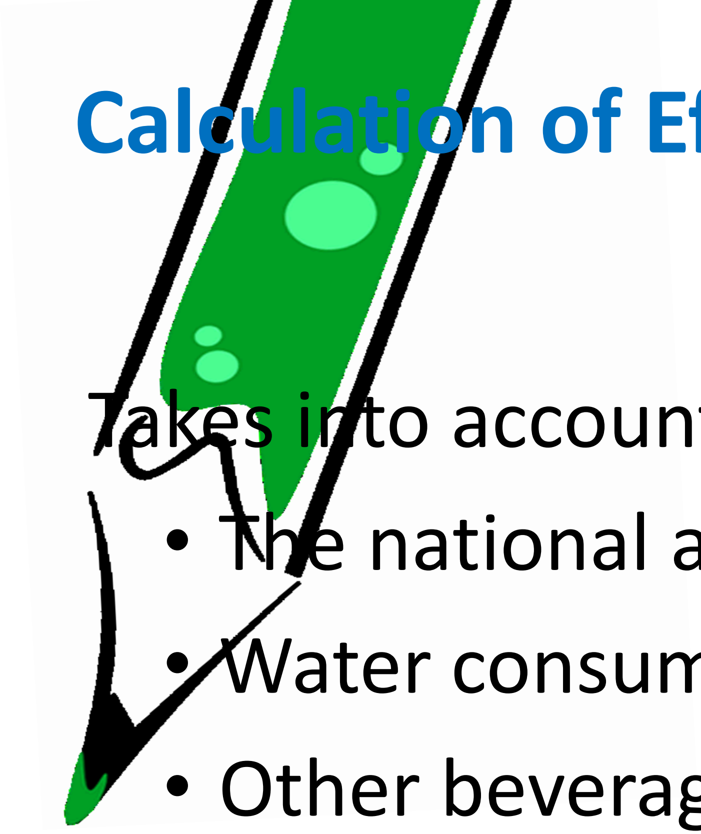


Requires periodic determinations of environmental radioactivity and radiation dose rates, such as:

- ambient radiation dose (external radiation; TLDs)
- activity concentration of radionuclides in drinking water and food (ingestion)
- activity concentration of radionuclides in aerosols (inhalation)
- radon indoors and outdoors (inhalation)

Such need justifies the set up of an **Environmental Monitoring Program:**

- With definition of samples to be analysed, sampling sites, frequency of sampling, radionuclides to be targeted, analytical protocols , …
- Delivery of an annual report with the results and dose assessment.



Calculation of Effective Dose to the average member of the public nationwide

Takes into account:

- The national average diet (Food balance sheet)
- Water consumption
- Other beverages and special food items (if needed)
- External radiation exposure (varies with regions)
- Exposure from Inhalation

Calculation of Effective Dose to the member of the public nationwide

Takes in consideration:

-natural radiation background (natural radionuclides)

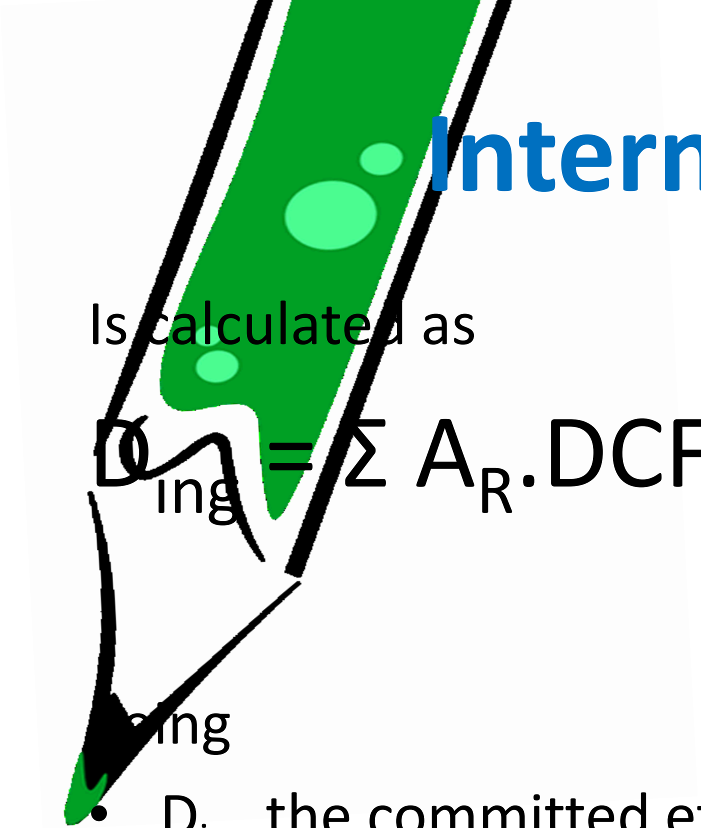
-prompts to identify additional exposures (artificial radionuclides and, in some areas, enhanced concentrations of natural radionuclides)

Effective dose

The **total committed effective dose**, H, is computed as

H = Dinh (inhalation)+ Ding (ingestion) + Dext (ambient radiation)

- H can be reported in mSv/y
- The external irradiation is measured directly as ambient radiation dose rate.
- Dose through Inhalation requires aerosol monitoring and radon measurements
- Dose from Ingestion requires analysis of radionuclides in foods and water.



Internal dose from ingested food

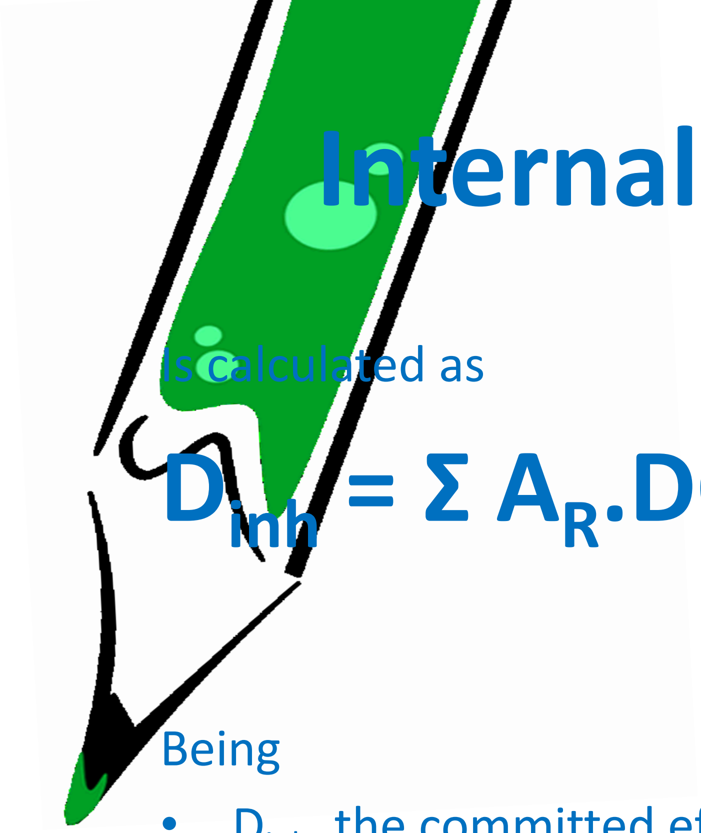
Is calculated as

$$D_{ing} = \Sigma\, A_R . DCF_{ingR} . Ing_r .$$

ing

- D_{ing} the committed effective dose from radionuclides in the ingested food in one year and expressed in Sv/y,
- A_R the activity concentration of radionuclide R in the ingested food , in Bq/kg,
- $DCF_{inhR,}$ the activity-to-dose conversion factor through ingestion of radionuclide R, in Sv/Bq,
- $Ing_{r,}$ the food ingestion rate in kg/y

Internal dose from aerosol inhalation



Is calculated as

$$D_{inh} = \Sigma\ A_R . DCF_{inhR} . C_d . Inh_r . . \ T$$

Being

- D_{inh} the committed effective dose from radionuclides in the inhaled dust and expressed in Sv/y,
- A_R the activity concentration of radionuclide R in the inhaled dust, in Bq/kg,
- DCF_{inhR} The activity-to-dose conversion factor through inhalation of radionuclide R, in Sv/Bq,
- $C_{d,}$ the air dust concentration, in kg/m^3,
- $Inh_{r,}$ the breathing rate in m^3/h,
- T the exposure time in hours per year.

Annual Effective Dose to the member of the public nationwide

- Usually, over the years radiations doses are mostly due to the natural radioactive background
- Are about 2.4-2.6 mSv/y, but vary between regions (geology and radon) and are higher in uranium mining areas
- Small contributions from artificial radionuclides present in the environment (1-10%)
- Larger contributions from artificial radionuclides following nuclear accidents.

Chernobyl nuclear accident (26 April 1986)

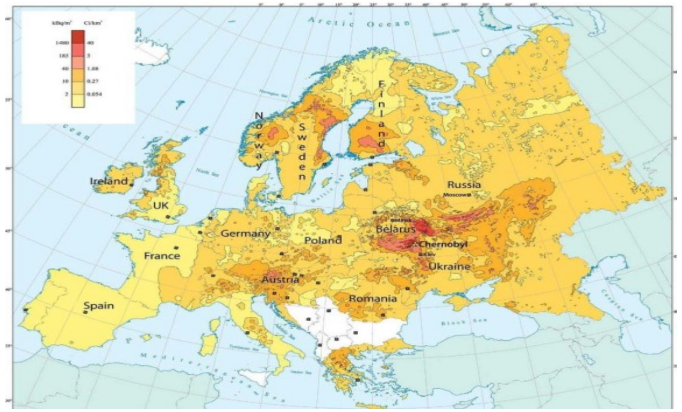
Calculation of Effective Dose to the member of the public nationwide

Routine EMP measurements in the country, and across Europe, allowed local and regional dose assessment.

Dose increased 1-3 mSv/y from fallout.

Advantages of a routine EMP:

- Rapid identification of radionuclides and specific transfer pathways:
  - imported carcasses with high 137Cs content , from East Europe
  - Migratory birds (dove and stournels) from Black Sea region
  - Dry fruits, seeds, and mushrooms from Midle East.
  - Powder milk from central Europe.
- Protection measures approved and implemented timely.



Fukushima nuclear accident (11 March 2011):

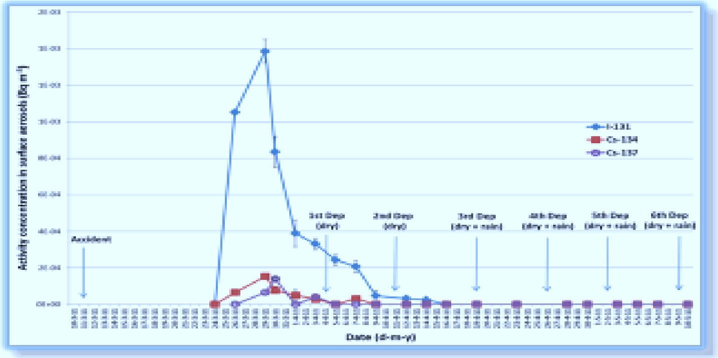
Calculation of Effective Dose to the average member of the public nationwide

Routine EMP provided timely measurements in the country, and across Europe, and allowed local and regional dose assessment.

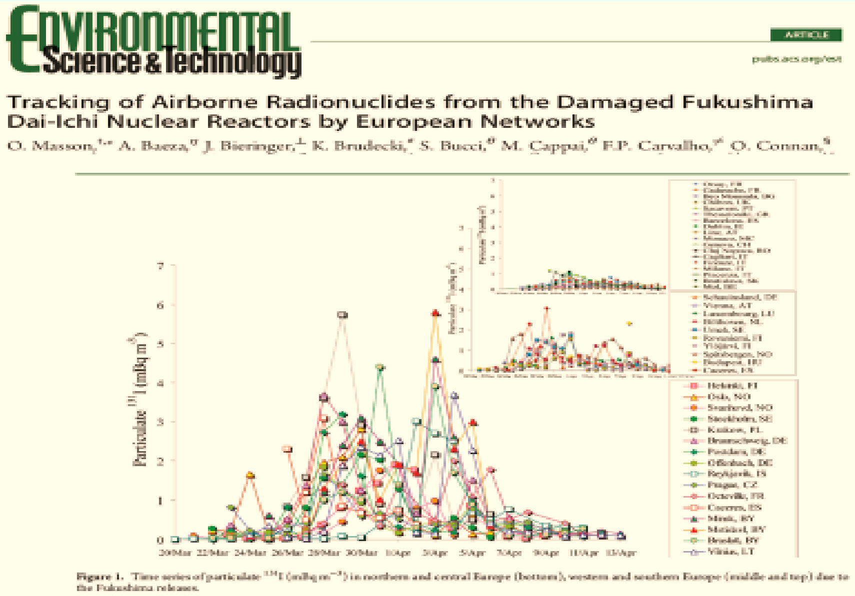
Advantages of EMP:

- A sound basis for decision on radiation protection measures
- Exposure to the public was estimated at 4% of the radiological impact from Chernobyl
- Practically no measures were needed. Approved to keep monitoring commodities imported from Japan.

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. Env. Radioactivity 2012)


Environmental Science & Technology

ARTICLE

pubs.acs.org/est

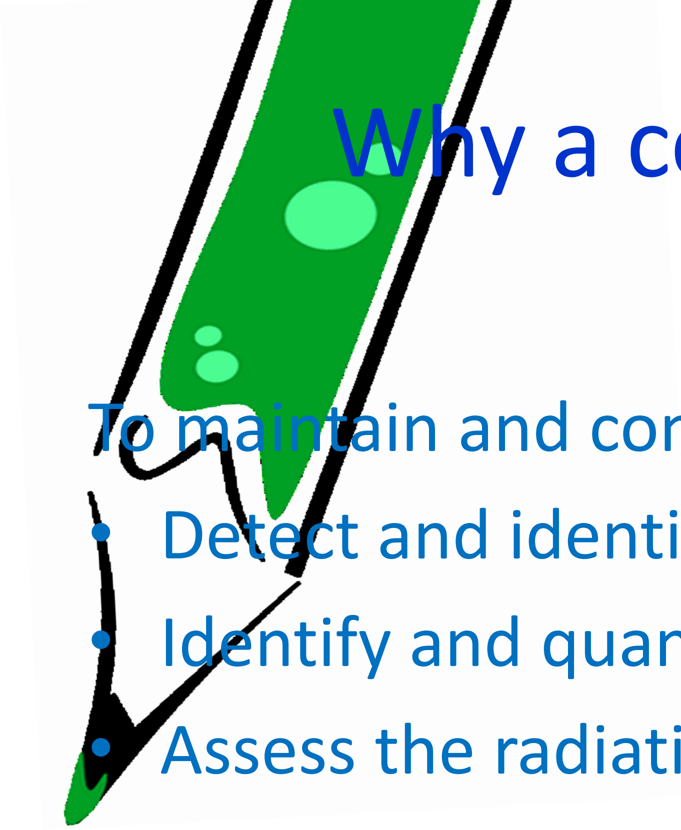
Tracking of Airborne Radionuclides from the Damaged Fukushima Dai-Ichi Nuclear Reactors by European Networks

Effective Dose to the member of the public nationwide

The lesson to learn from nuclear accidents is:

- Continued monitoring and dose assessment are needed because there are many radioactive sources (nuclear and non-nuclear) with regular discharges into the environment, and accidental releases may occur.
- An EMP is needed to ensure radiation safety of the population.

Why a continuous Environmental Radiation Monitoring Program?



To maintain and continuously improve the ability to:

- Detect and identify and nuclear or radiological emergency
- Identify and quantify radionuclides present
- Assess the radiation dose to humans
- Enable sound decisions
- Act timely with radiation protection measures

If there is no EMP:
What risk assessment can we make ?
What advices to the population? Decisions? Measures?

Conclusions

- Ingestion of radionuclides with the diet originates internal exposure of organs and tissues, giving a large contribution to the radiation dose received by humans
- The diet may include a large variety of foods from different origins. Foods may contain variable radionuclide concentrations (natural and artificial) depending on discharges into the environment in the regions of production.
- To fully assess the radiation exposure of the public, the determination of radioactivity in the diet (ingestion), radioactivity in the air (inhalation) and external (ambient) radiation are needed
- Many countries, following the IAEA recommendations, implement Environmental Monitoring Programms.

Co-funded by the Erasmus+ Programme of the European Union

Thank you for your kind attention!

Fernando P. Carvalho, PhD
E-mail: carvalho@ctn.tecnico.ulisboa.pt

TÉCNICO LISBOA

MENV PRO