Understanding The Basics of Radioecology

1) What is radioecology
2) Mechanisms of bioaccumulation
3) Dose and Exposure

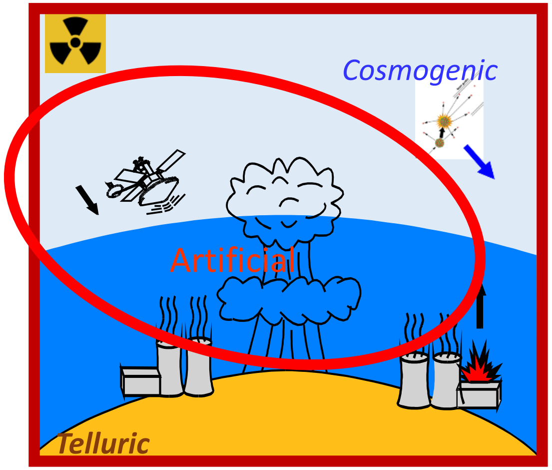
What is Marine Radioecology?

- A specialized discipline of **marine ecology** which studies how **radioactive substances** interact with the marine environment, and how different mechanisms and processes affect **radionuclide migration** in the marine food chain and ecosystem.

- Includes aspects of field sampling, designed field and laboratory radiotracer experiments, the development of predictive simulation models, and dose assessments to man and biota.

- Requires basic knowledge of biology, ecology, chemistry, geology, biogeochemistry, oceanography, and radiation protection.

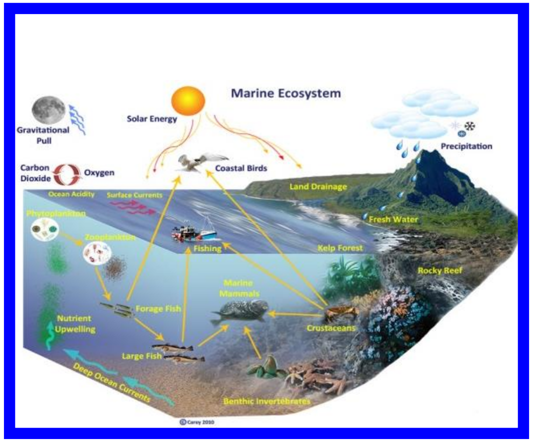
I. Sources



II. Humans

III. Bioaccumulation

IV. Risk Assessment/ Management



Ecosystem http://www.farmingtonglenn.net/why-i-believe/
Crowd : http://blog.world-first.co.uk/wp-content/uploads/2011/11/Crowd-of-people-at-airport.jpg

I. Sources: There are three major sources of radionuclides that enter the Marine Environment:

1) **U-Th series radionuclides** – created during element formation and now produce a series of "daughter" radionuclides via radioactive decay. Examples: ^{238}U, ^{235}U, and ^{232}Th

2) **Cosmogenic Radionuclides** – continuously being created by cosmogenic rays that interact with materials on Earth. Examples: ^{14}C, ^{7}Be

3) **Artificial Radionuclides** –being produced by mainly past bomb-testings, reprocessing plant discharges, nuclear accidents. Examples: ^{90}Sr, ^{137}Cs, ^{239,240}Pu, ^{238}Pu…

These radionuclides enter the marine system as both point and non-point sources and their distributions are controlled by their reactivity (both chemical and biological) and their half-lives.

II. Lets’s first go to the dose calculations to human

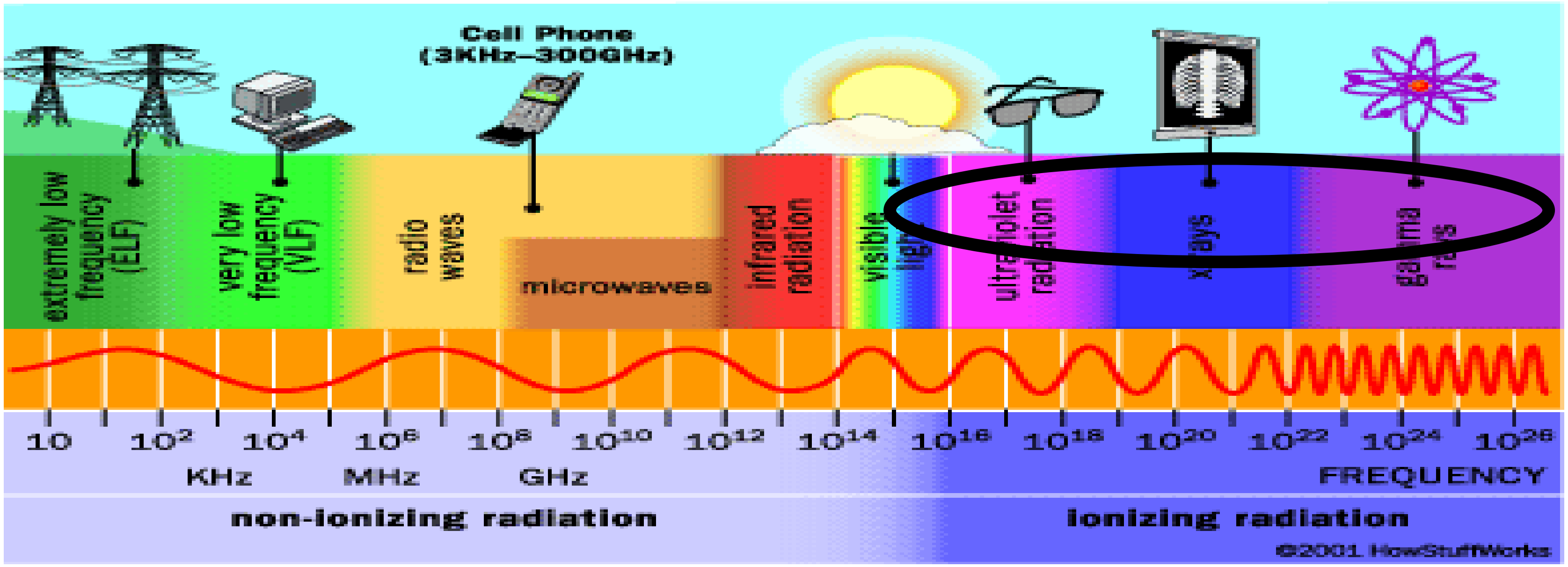
What is radiation?

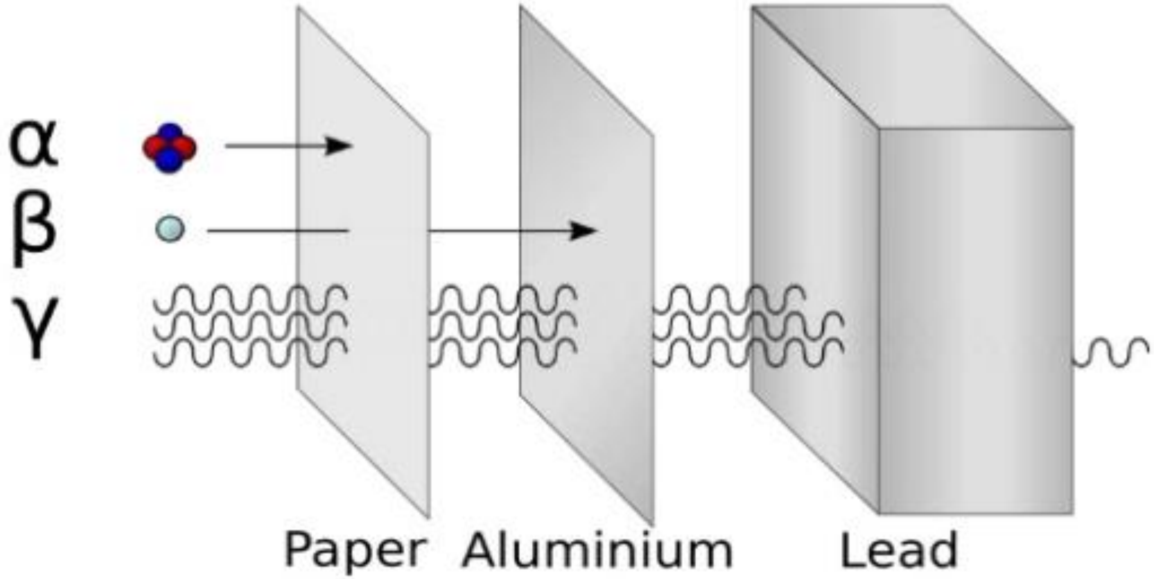
Radiation is energy in the form of high speed particles or electromagnetic waves. It can be ionizing or non-ionizing. Non-ionizing radiation lacks the energy to alter atoms (e.g., visible light and microwaves). ***Ionizing radiation has enough energy to change normal cellular functioning.*** Ionizing radiation may cause cells to die or transform into a cancerous cell. Ionizing radiation is categorized by its strength or energy level:

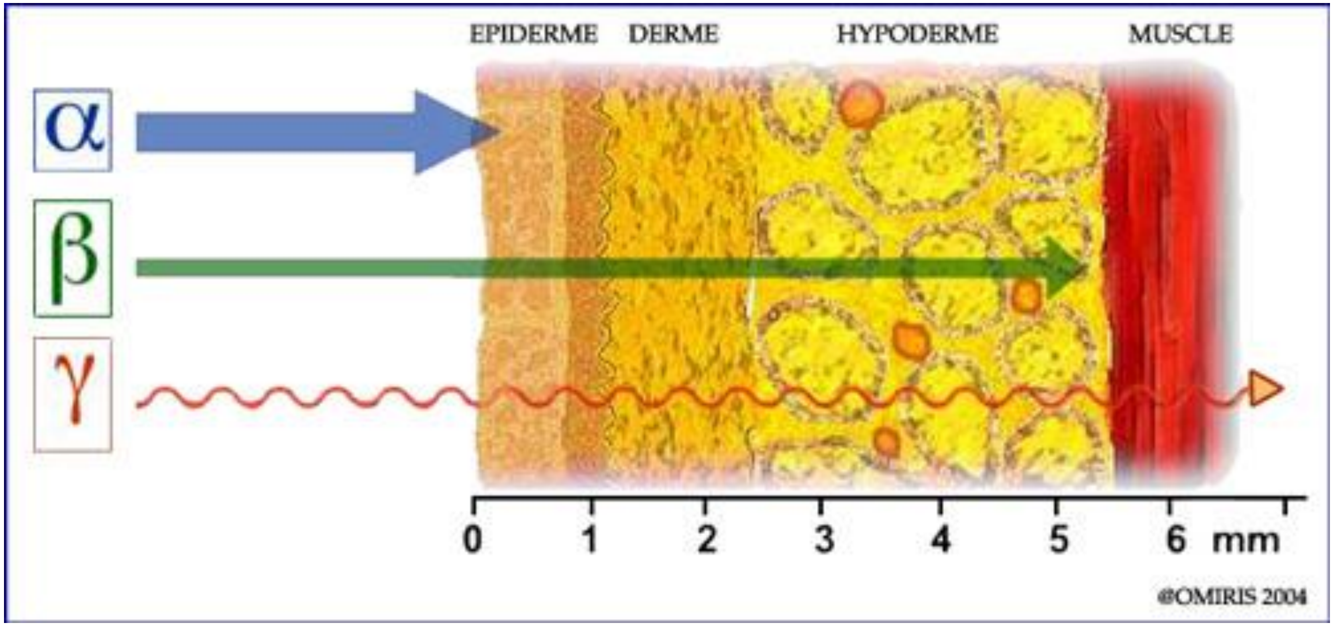
“excitation of electrons”

Low Energy

High Energy




α
β
γ
Paper
Aluminium
Lead


EPIDERME
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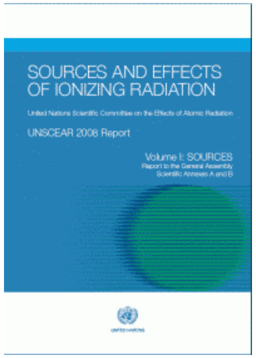
@OMIRIS 2004

DEVELOPMENT OF INTERNATIONAL STANDARDS

SCIENCE
Doses and effects

➔ **UNSCEAR**



SOURCES AND EFFECTS OF IONIZING RADIATION

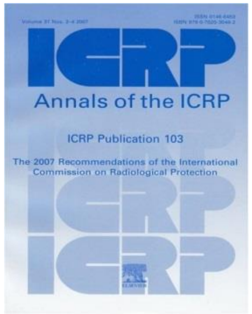
United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2008 Report

Volume I: SOURCES
Report to the General Assembly
Scientific Annexes A and B

PRINCIPLES
Philosophy and policy

➔ **ICRP**



ICRP

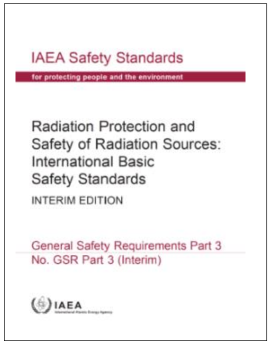
Annals of the ICRP

ICRP Publication 103

The 2007 Recommendations of the International Commission on Radiological Protection

STANDARDS
Nuclear Safety and Security

➔ **IAEA**



IAEA Safety Standards
for protecting people and the environment

Radiation Protection and
Safety of Radiation Sources:
International Basic
Safety Standards

INTERIM EDITION

General Safety Requirements Part 3
No. GSR Part 3 (Interim)

IAEA

Radiation Dose Concepts

- Adsorbed dose (**Gray, Gy**) is absorption of radiation energy per unit mass of tissue. 1 Gy = 1 Joule per kg

- Equivalent dose (**Sievert, Sv**) adjusts for biological damage by different types of ionizing radiation using a "quality factor"

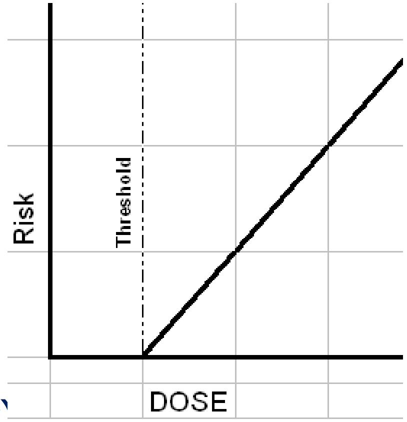
  QF 1 (β,γ,X) and 20 (α)

- Effective dose (**Sievert, Sv**) weights equivalent dose by tissue-specific factors to create a dose figure that standardizes risk

DETERMINISTIC AND STOCHASTIC EFFECTS

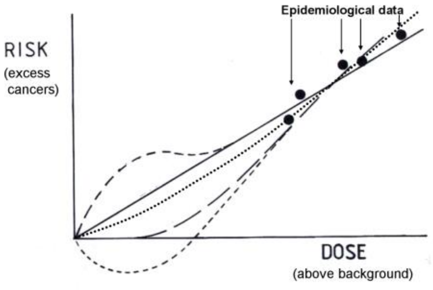
- **Deterministic effects:** Early or late effects that have a dose-effect relationship, *i.e.*, a threshold dose and an increase in effect with increasing dose.

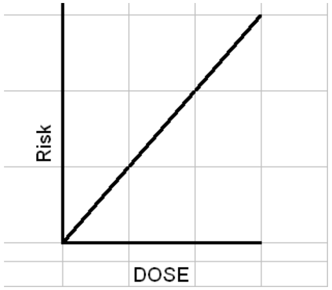
  - Harmful, mostly late, tissue reactions
  - Mostly due to cell killing above a threshold (100 mGy or more)
  - New data on **eye** : new dose limit for occupational exposure (**20 mSv/y** instead of 150 mSv/y)



- **Stochastic effects:** Long-term random or chance effects – there is no relationship and no lower threshold dose for effects.

  - Cancer and heritable disease
  - **Assumption Linear No Threshold**





EFFECTIVE DOSE: FROM ABSORBED DOSE TO ASSESSMENT OF RISK

Mean absorbed dose imparted to tissue (Gy or Sv)

Equivalent dose

$$E = \sum_{T} w_{T} H_{T} = \sum_{T} w_{T} \sum_{R} w_{R} \; D_{T,R}$$

Radiation quality

Effective dose

Tissue radiosensitivity

- **Linear no threshold (LNT) dose-risk relationship**
- **Stochastic effects**
- **Not measurable quantity**

Credit A. Rannou, IRSN

RADIATION WEIGHTING FACTORS (W_R) ACCORDING TO ICRP

Type and energy range	ICRP 60 1991	ICRP 103 2007
γ rays	**1**	**1**
β particles	**1**	**1**
α particles	**20**	**20**

TISSUE WEIGHTING FACTORS (W_T) ACCORDING TO ICRP-103 (2007)

Tissue	W_T	ΣW_T
Bone-marrow (red) , colon, lung, stomach, breast, remainder tissues (14)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04

Irradiation versus contamination

- Irradiation =

body exposed to external radiation (soil, air)

AT DISTANCE

- Contamination : radioactive substance

on the skin (external) and within the body (internal)

Dose assessment parameters for ingestion pathway

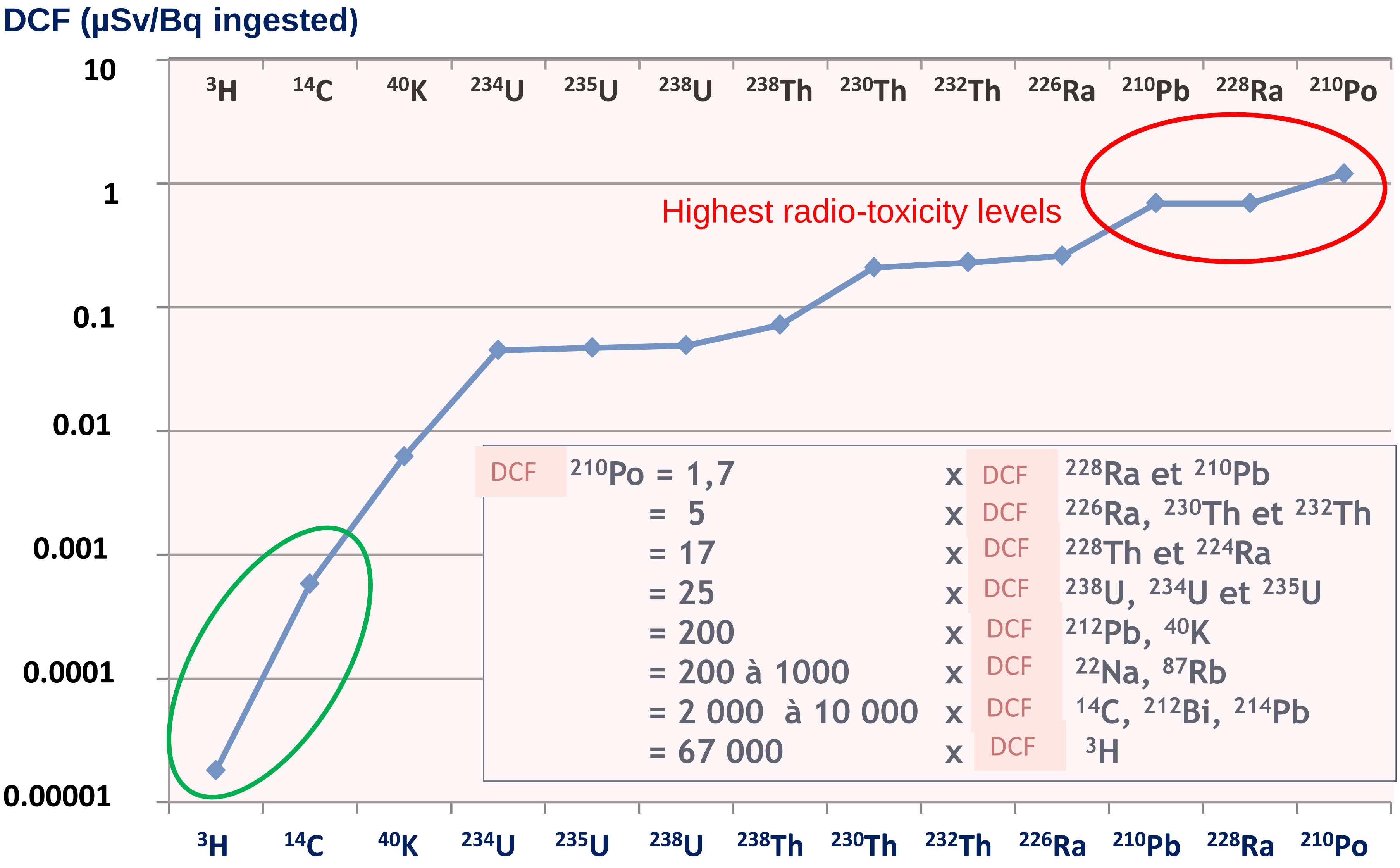
$$D_{\text{eff-ing}} = \Sigma_i \, \Sigma_j \quad A_{i,j} \quad \text{x} \quad Q_j \quad \text{x} \quad DCF_i$$

$D_{\text{eff-ing}}$	effective dose by ingestion	Sv/y
A_{ij}	radionuclide i massic activity in foodstuff j	Bq/kg
Qj	Consumption rate of foodstuff j	kg/y
DCFi	Dose Conversion Factor for radionuclide i	Sv/Bq ingested

Specific Cases:
The potassium concentration is kept constant by humans. The proportion of ^{40}K to total K (specific activity: Bq/kg of potassium) is also constant. So the ^{40}K whole body activity is constantand leads to to an effective dose of ~ 170 µSv/y for an adult (185 µSv/y for a child)

For similar reasons, ^{14}C activity is constant in the human body. This leads to an annual effective dose of ~12 µSv/an.

Dose conversion factors for some naturally occurring radionuclides



Highest radio-toxicity levels

DCF ^{210}Po = 1,7 x DCF ^{228}Ra et ^{210}Pb
= 5 x DCF ^{226}Ra, ^{230}Th et ^{232}Th
= 17 x DCF ^{228}Th et ^{224}Ra
= 25 x DCF ^{238}U, ^{234}U et ^{235}U
= 200 x DCF ^{212}Pb, ^{40}K
= 200 à 1000 x DCF ^{22}Na, ^{87}Rb
= 2 000 à 10 000 x DCF ^{14}C, ^{212}Bi, ^{214}Pb
= 67 000 x DCF ^{3}H

Lowest radio-toxicity levels

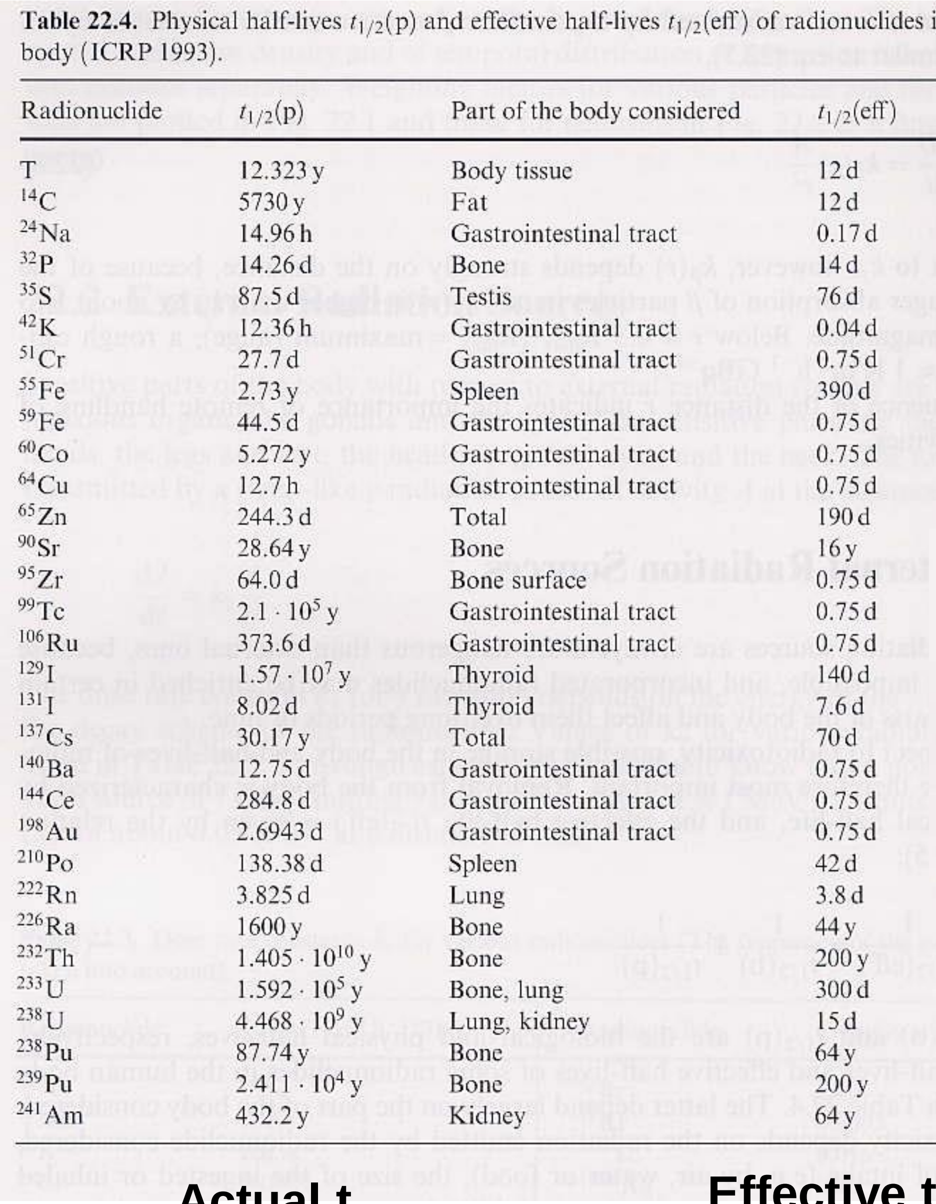


Table 22.4. Physical half-lives $t_{1/2}(p)$ and effective half-lives $t_{1/2}(eff)$ of radionuclides in the human body (ICRP 1993).

Radionuclide	$t_{1/2}(p)$	Part of the body considered	$t_{1/2}(eff)$
T	12.323 y	Body tissue	12 d
^{14}C	5730 y	Fat	12 d
^{24}Na	14.96 h	Gastrointestinal tract	0.17 d
^{32}P	14.26 d	Bone	14 d
^{35}S	87.5 d	Testis	76 d
^{42}K	12.36 h	Gastrointestinal tract	0.04 d
^{51}Cr	27.7 d	Gastrointestinal tract	0.75 d
^{55}Fe	2.73 y	Spleen	390 d
^{59}Fe	44.5 d	Gastrointestinal tract	0.75 d
^{60}Co	5.272 y	Gastrointestinal tract	0.75 d
^{64}Cu	12.7 h	Gastrointestinal tract	0.75 d
^{65}Zn	244.3 d	Total	190 d
^{90}Sr	28.64 y	Bone	16 y
^{95}Zr	64.0 d	Bone surface	0.75 d
^{99}Tc	$2.1 \cdot 10^5$ y	Gastrointestinal tract	0.75 d
^{106}Ru	373.6 d	Gastrointestinal tract	0.75 d
^{129}I	$1.57 \cdot 10^7$ y	Thyroid	140 d
^{131}I	8.02 d	Thyroid	7.6 d
^{137}Cs	30.17 y	Total	70 d
^{140}Ba	12.75 d	Gastrointestinal tract	0.75 d
^{144}Ce	284.8 d	Gastrointestinal tract	0.75 d
^{198}Au	2.6943 d	Gastrointestinal tract	0.75 d
^{210}Po	138.38 d	Spleen	42 d
^{222}Rn	3.825 d	Lung	3.8 d
^{226}Ra	1600 y	Bone	44 y
^{232}Th	$1.405 \cdot 10^{10}$ y	Bone	200 y
^{233}U	$1.592 \cdot 10^5$ y	Bone, lung	300 d
^{238}U	$4.468 \cdot 10^9$ y	Lung, kidney	15 d
^{238}Pu	87.74 y	Bone	64 y
^{239}Pu	$2.411 \cdot 10^4$ y	Bone	200 y
^{241}Am	432.2 y	Kidney	64 y

Actual $t_{½}$

Effective $t_{½}$

Radiotoxicity

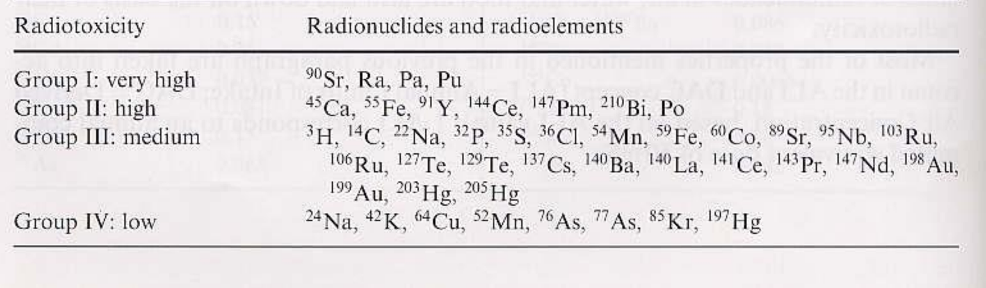


Table 22.5. Radiotoxicity of radionuclides and radioelements.

Radiotoxicity	Radionuclides and radioelements
Group I: very high	^{90}Sr, Ra, Pa, Pu
Group II: high	^{45}Ca, ^{55}Fe, ^{91}Y, ^{144}Ce, ^{147}Pm, ^{210}Bi, Po
Group III: medium	^{3}H, ^{14}C, ^{22}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{54}Mn, ^{59}Fe, ^{60}Co, ^{89}Sr, ^{95}Nb, ^{103}Ru, ^{106}Ru, ^{127}Te, ^{129}Te, ^{137}Cs, ^{140}Ba, ^{140}La, ^{141}Ce, ^{143}Pr, ^{147}Nd, ^{198}Au, ^{199}Au, ^{203}Hg, ^{205}Hg
Group IV: low	^{24}Na, ^{42}K, ^{64}Cu, ^{52}Mn, ^{76}As, ^{77}As, ^{85}Kr, ^{197}Hg

Depends on:

Radiation emitted

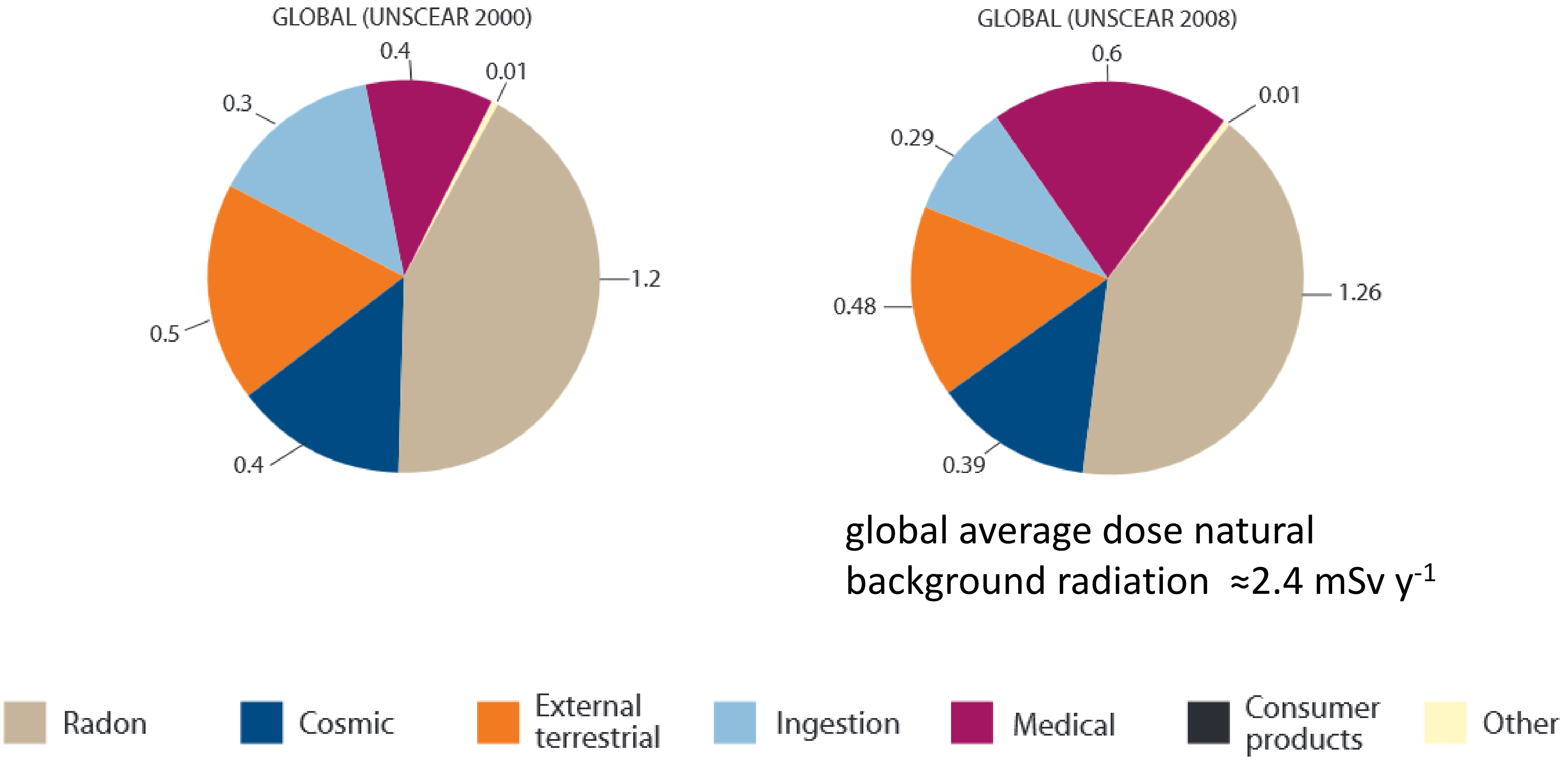
Mode of intake

Amount

Chemical prop./metabolic affinity

Effective $t_{½}$

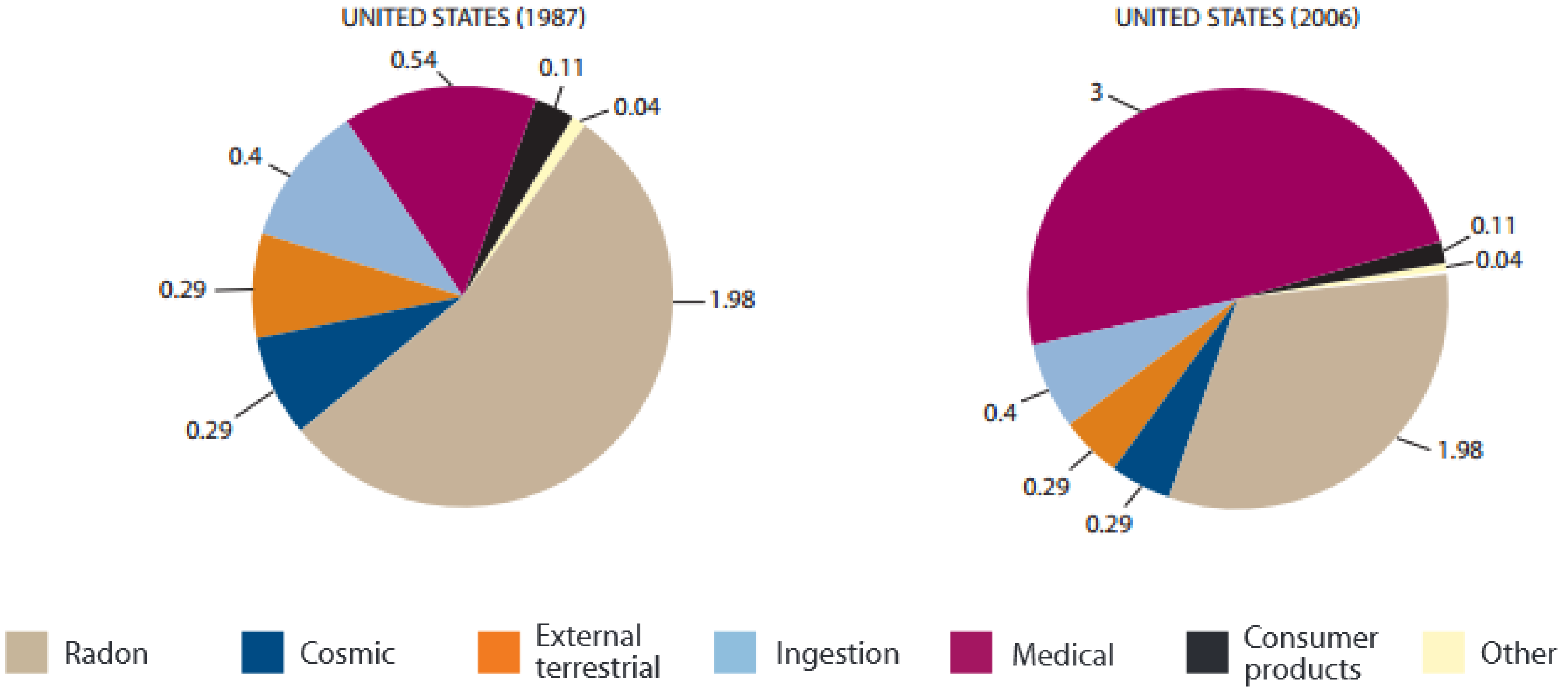
Worldwide average exposures from various sources



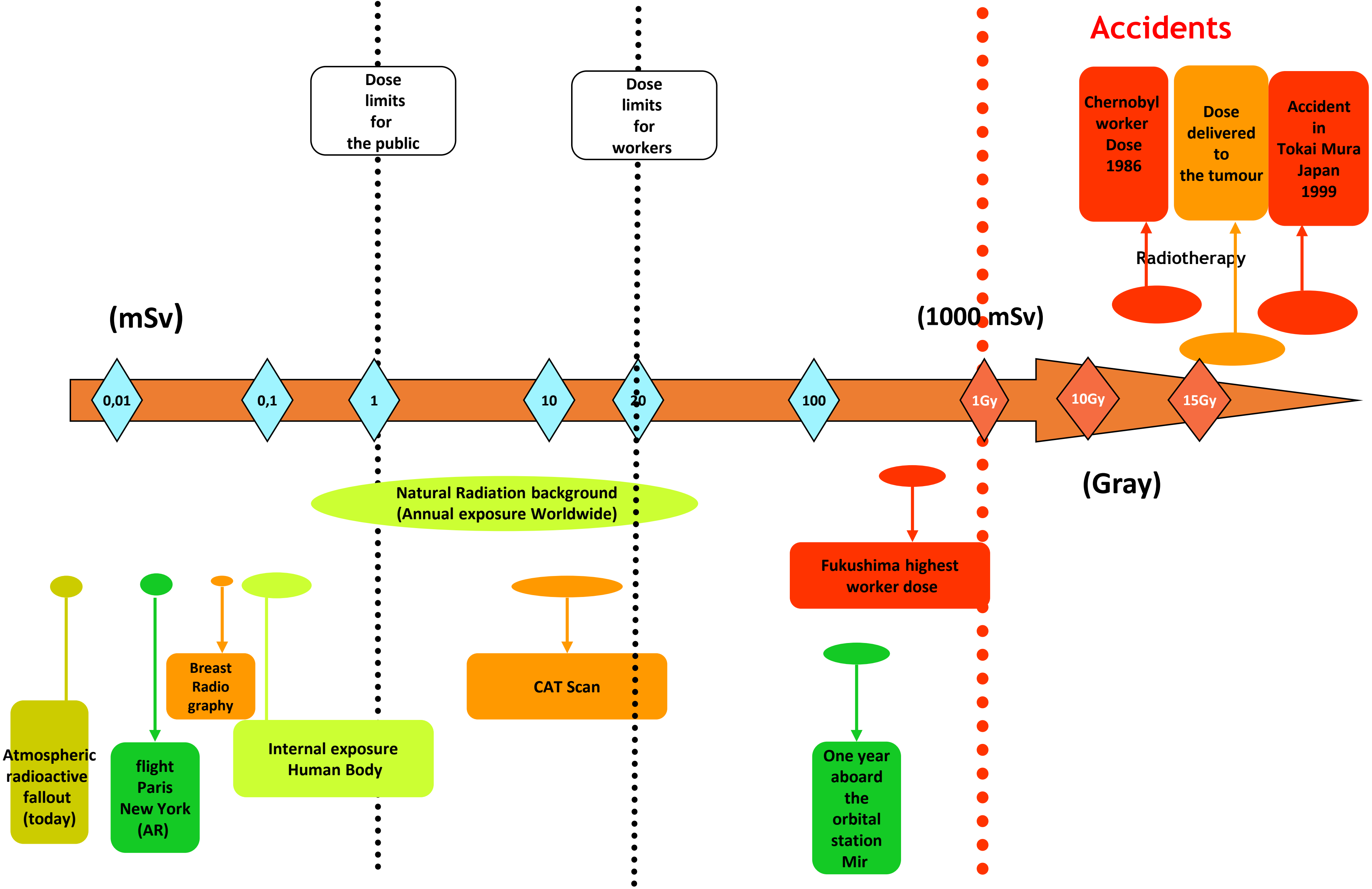
global average dose natural background radiation ≈2.4 mSv y^{-1}

However exposure of the public to ionizing radiation varies among countries and inside countries. It greatly depends on location and way of life.

Average Exposure of Public to Ionizing Radiation in the United States
Increasing dose from medical



HUMAN EXPOSURE TO IONIZING RADIATION



Dose
limits
for
the public

Dose
limits
for
workers

Accidents

Chernobyl
worker
Dose
1986

Dose
delivered
to
the tumour

Accident
in
Tokai Mura
Japan
1999

Radiotherapy

(mSv)

(1000 mSv)

0,01

0,1

1

10

20

100

1Gy

10Gy

15Gy

(Gray)

Natural Radiation background
(Annual exposure Worldwide)

Fukushima highest
worker dose

Atmospheric
radioactive
fallout
(today)

flight
Paris
New York
(AR)

Breast
Radio
graphy

Internal exposure
Human Body

CAT Scan

One year
aboard
the
orbital
station
Mir

III. Now that we understand exposure and dose, let’s look specifically at marine radioecology and the processes of bioaccumulation.

Radionuclide transfer in marine food webs

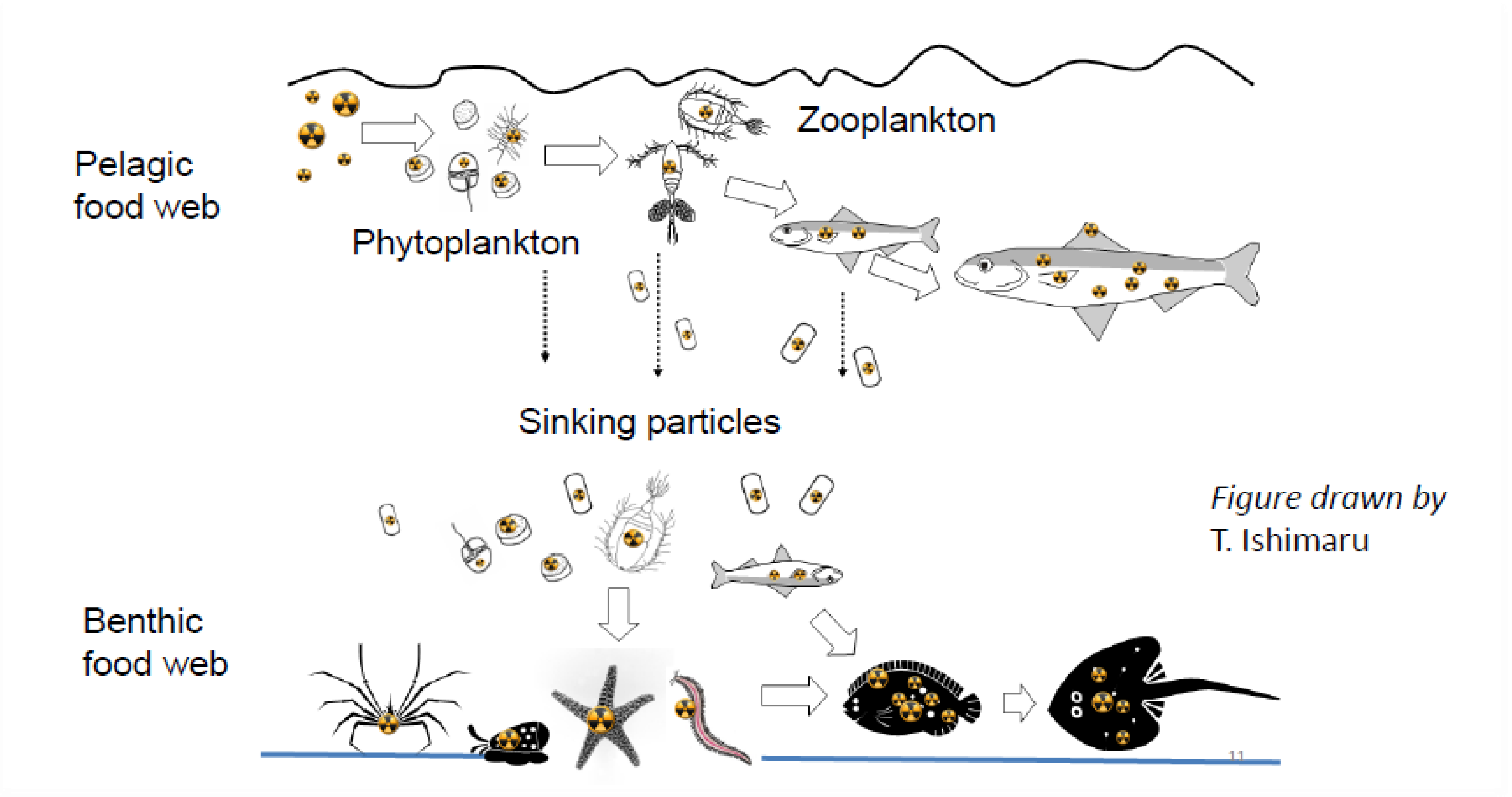
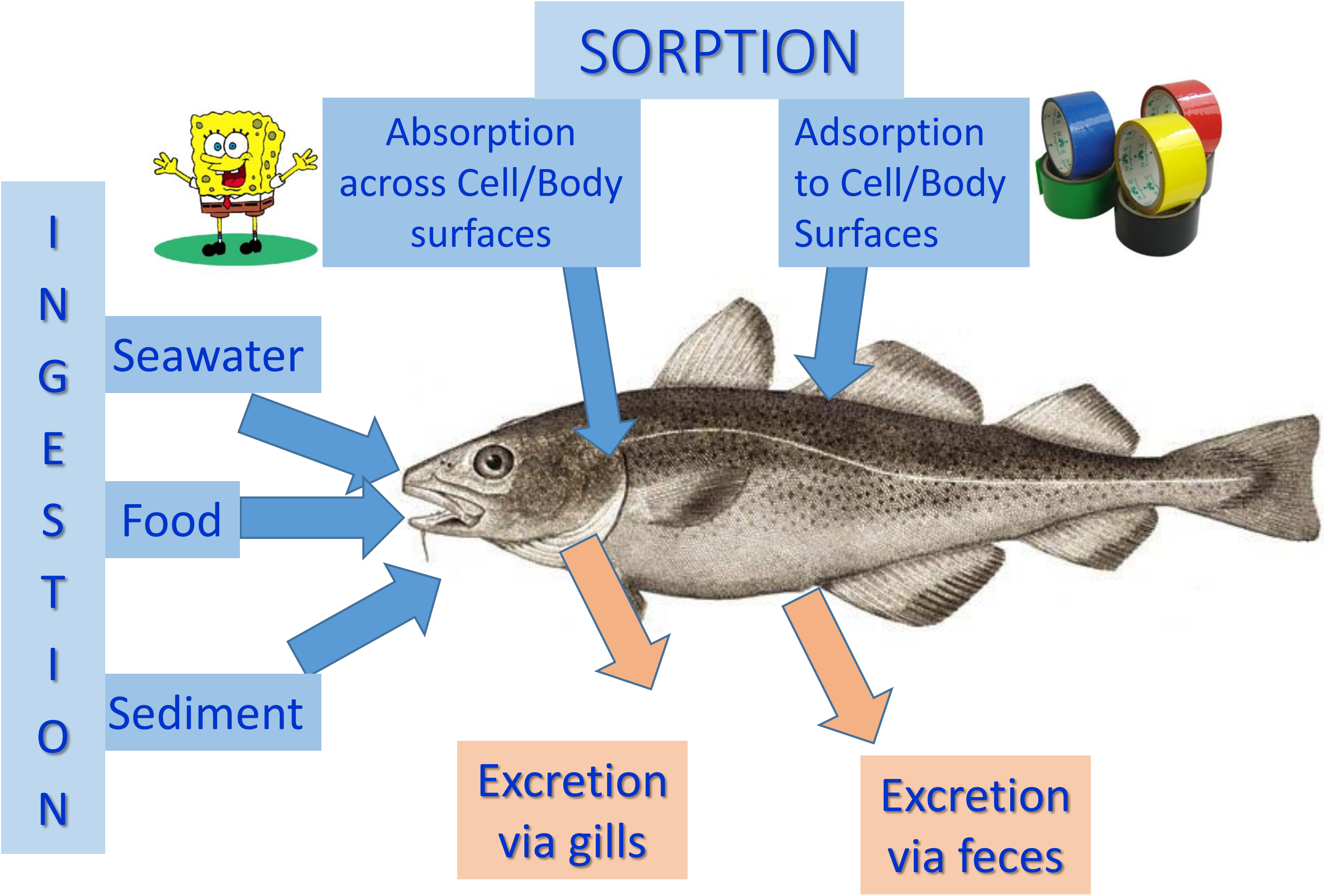


Figure drawn by
T. Ishimaru

How Are Radionuclides Taken Up By Marine Organisms?



SORPTION

Absorption across Cell/Body surfaces

Adsorption to Cell/Body Surfaces

INGESTION

Seawater

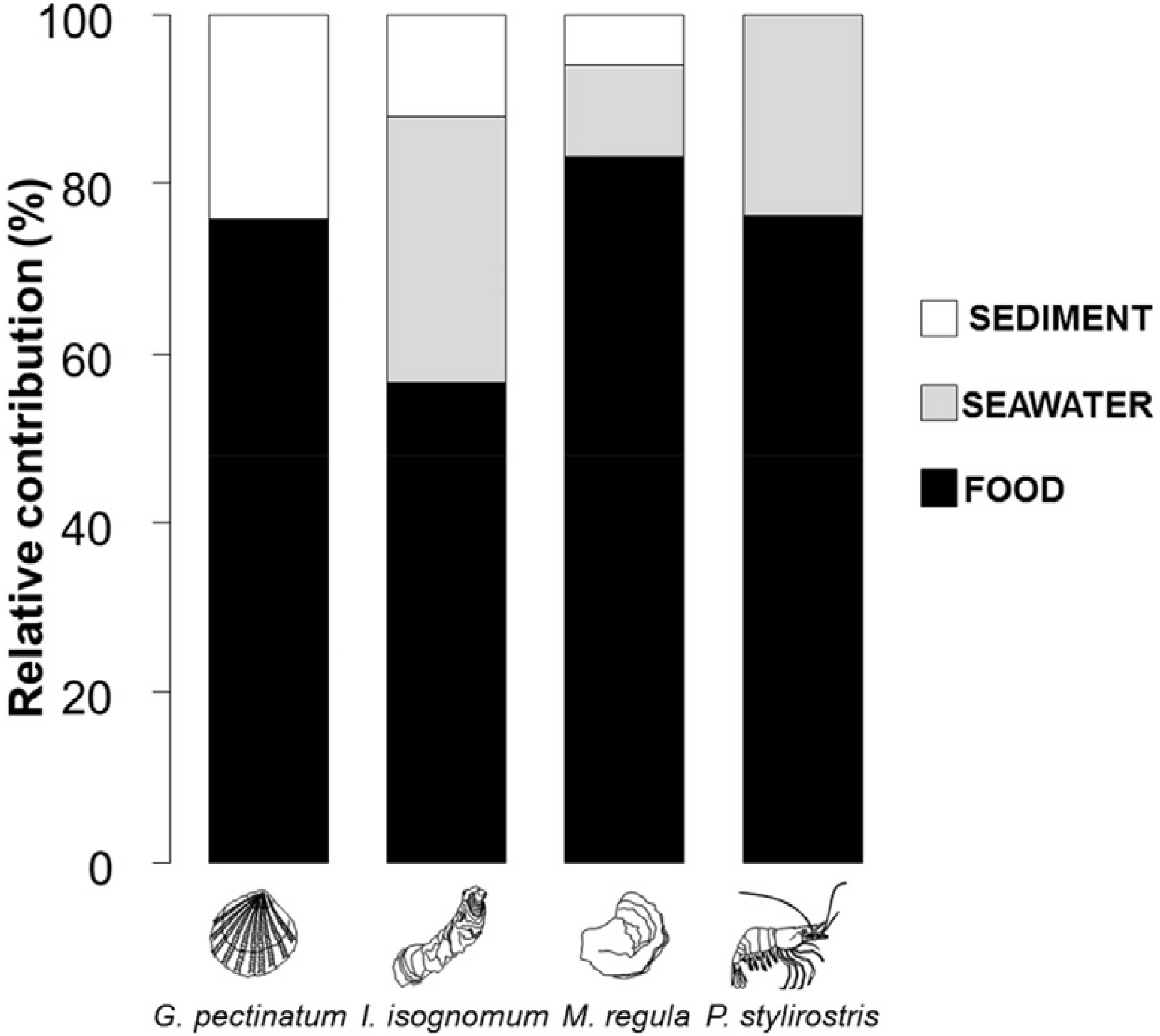
Food

Sediment

Excretion via gills

Excretion via feces

Relative contributions (%) of three uptake pathways (seawater, food and sediment) to the total bioaccumulation of ^{134}Cs in marine organisms



Metian et al.,
JER, 2016

Main Factors Affecting Bioaccumulation of Radionuclides

Environmental:

Temperature
Salinity
Trace Metal Competition
Oxidation State (chemical form)
Organic Complexation
Exposure Time

Biological:

Age, size
Sex
Reproductive State
Physiology & Metabolism
Food Type
Feeding Mode
Ingestion Rate
Filtering Rate
Assimilation Efficiency
External Tissue Composition

Credit Scott Fowler

Concentration Factor

Ratio of radionuclide concentration in organism to radionuclide concentration in ambient sea water

$$CF = \frac{\text{Bq g}^{-1}\text{ wet weight of organism}}{\text{Bq g}^{-1}\text{ sea water}}$$

***Assumptions*:**

- Generally refers to equilibrium situation
- Uptake is from soluble form in water

***Uses*:**

- Compare relative bioavailability of different radionuclides to a given organism
- Compare ability of different organisms to accumulate a given radionuclide
- Through models we can predict the resultant concentration in an organism if the concentration in sea water is known
- To identify potential “bioindicator organisms” for radionuclides

Transfer Factor

Ratio of radionuclide concentration in organism to radionuclide concentration in sediment or food

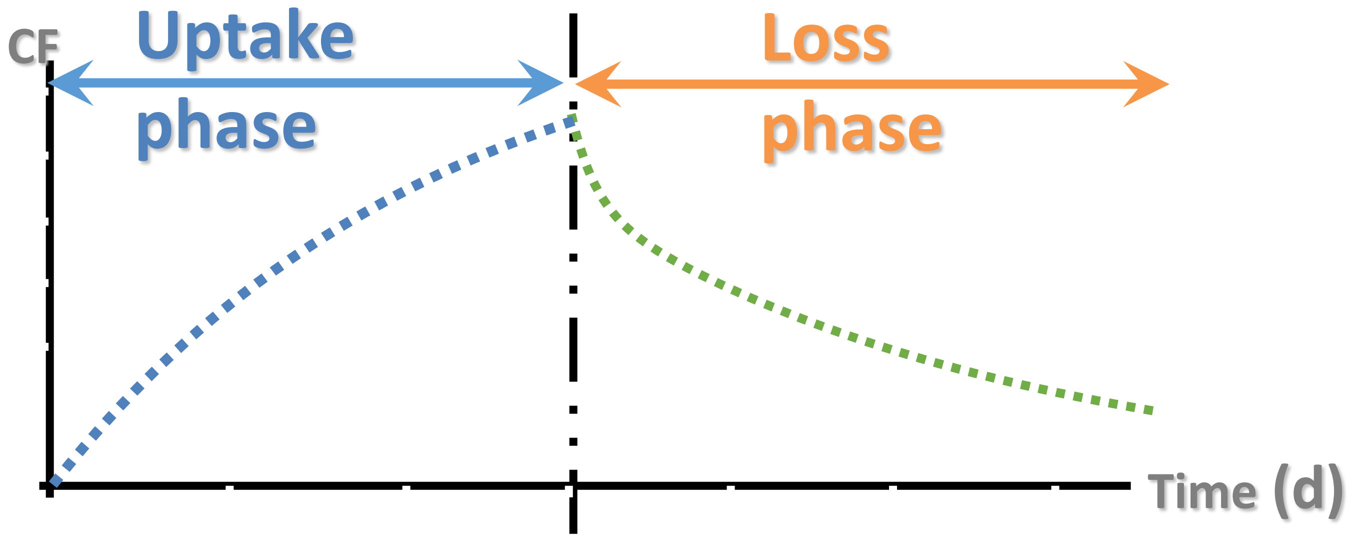
$$\mathbf{TF} = \frac{\text{Bq g}^{-1}\text{ wet weight of organism}}{\text{Bq g}^{-1}\text{ sediment or food}}$$

***Assumptions*:**

- Generally refers to equilibrium situation

Typical experimental procedure

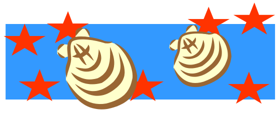
Contamination via Seawater



Contamination conditions

Closed circuit aquarium

- **Loss rate of metals (k_e)**



- **Metal retention (T b½)**

Uptake of Chemicals *(X days)*

Non-contamination conditions

Open circuit aquarium

- **CF, saturation if reached**

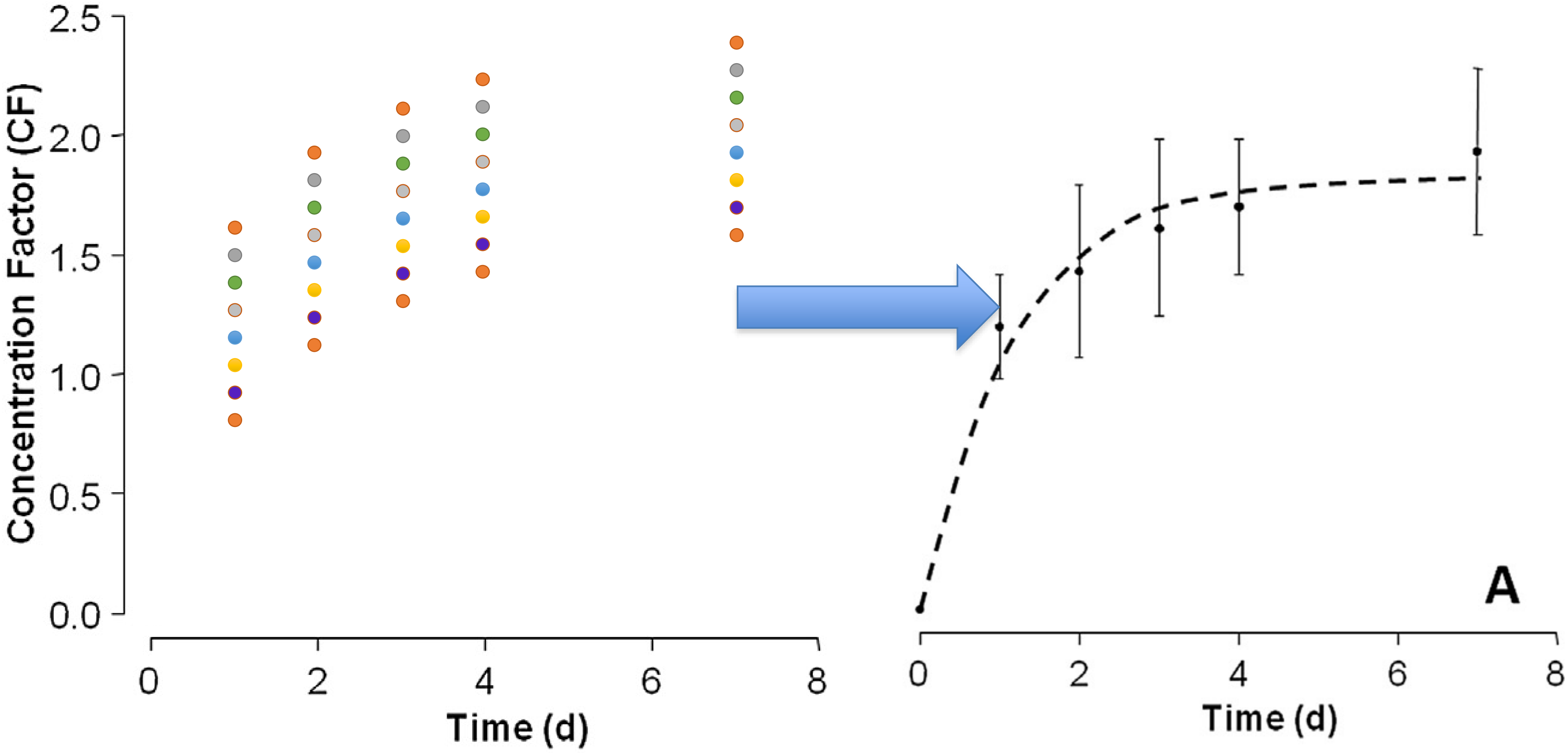
Loss of chemicals (X weeks)

- **Uptake rate of metals (k_u)**

Courtesy of Marc Metian, IAEA Research Scientist

From measurements to model: Uptake

Example: Uptake phase with n= 8 individuals



Courtesy of Marc Metian, IAEA Research Scientist

Uptake phase: kinetic parameters

- $CF_t = k_u * t$
- $CF_t = CF_{ss} * (1 - e^{-ket})$ and $CF_{ss} = k_u / k_e$

CF_t : the concentration factors at time t (d)

CF_{ss} : the concentration factors at steady state

k_u : uptake rate constant (d^{-1})

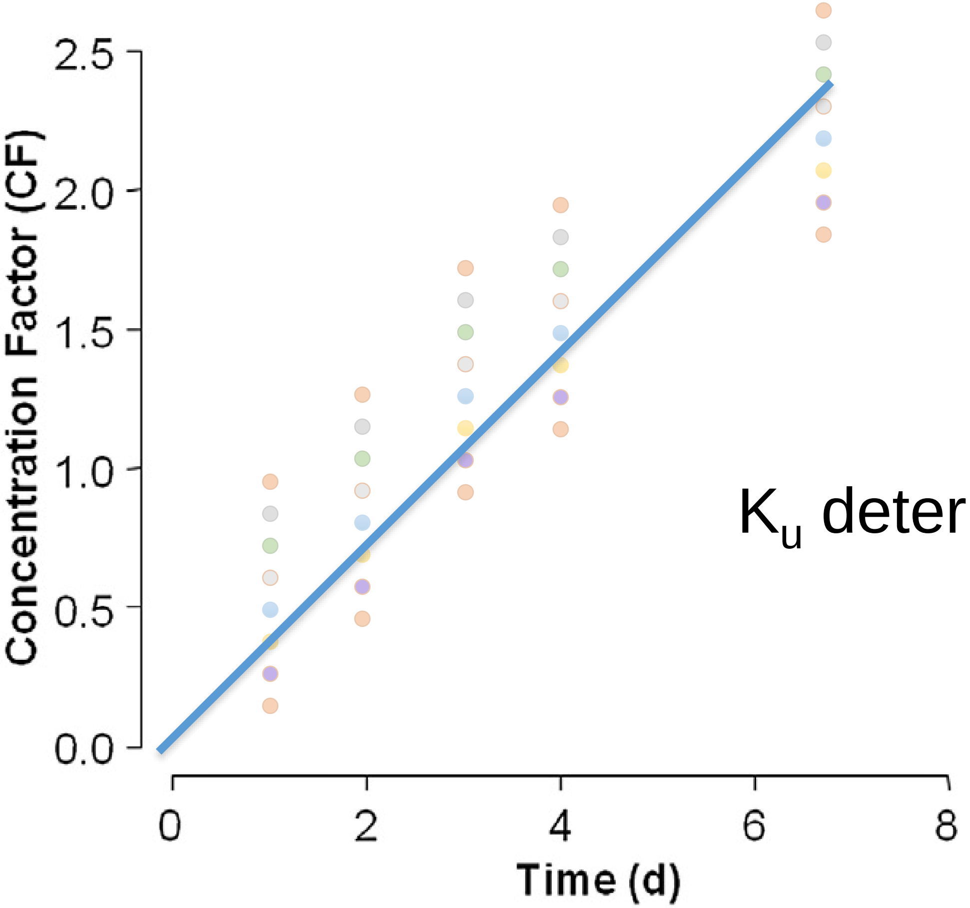
K_e : loss rate constant (d^{-1})

CF= activity ratio (see previous slides)

Courtesy of Marc Metian, IAEA Research Scientist

Uptake phase: kinetic parameters

- $CF_t = k_u * t$

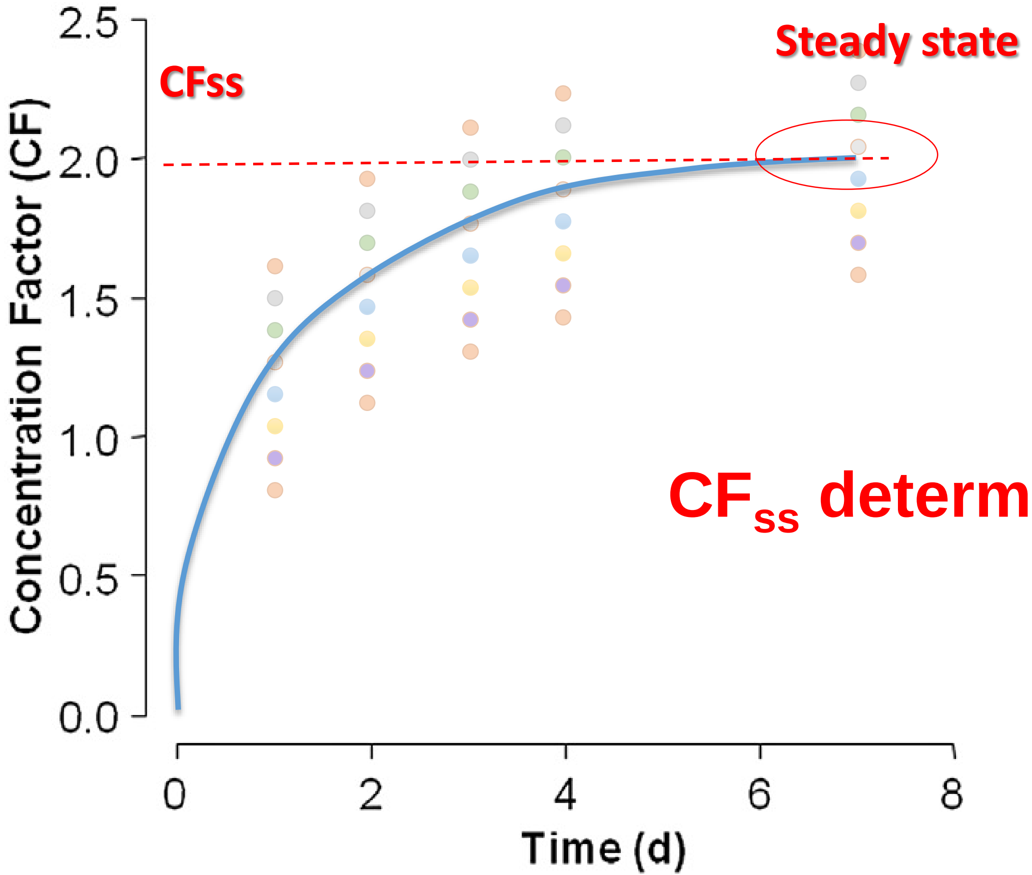


K_u determination

Courtesy of Marc Metian, IAEA Research Scientist

Uptake phase: kinetic parameters

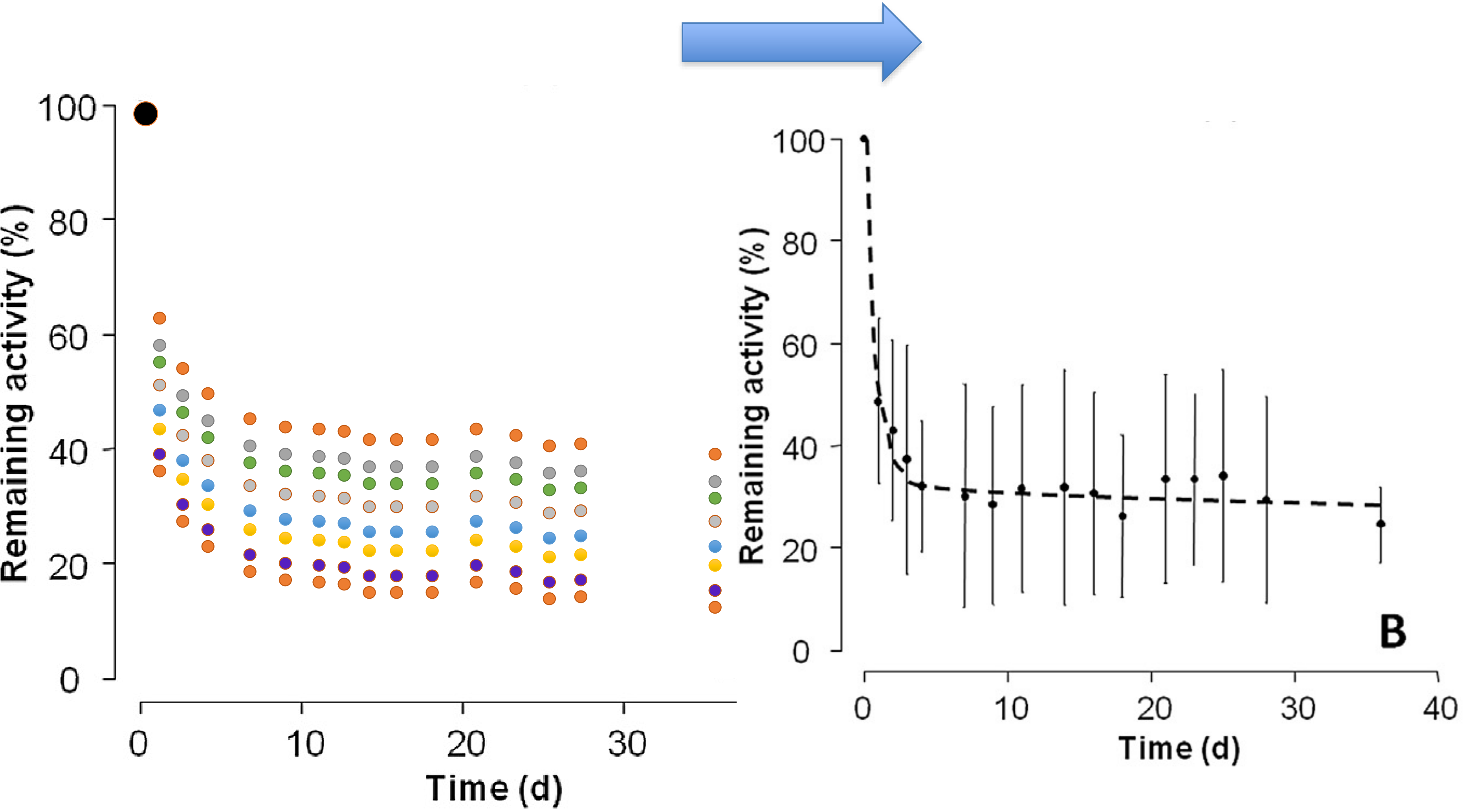
- $CF_t = CF_{ss} * (1 - e^{-ket}) \text{ and } CF_{ss} = k_u/k_e$



CF_{ss} determination

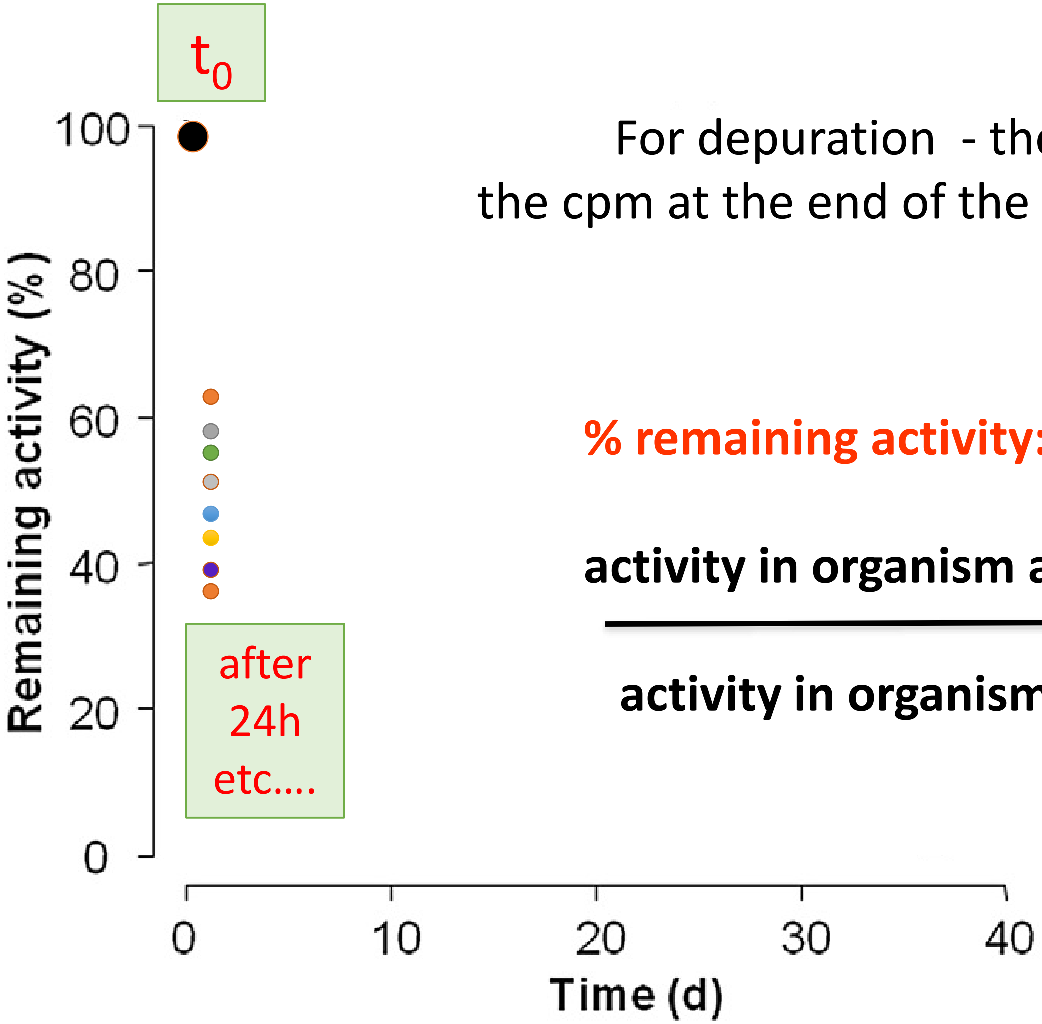
Courtesy of Marc Metian, IAEA Research Scientist

From measurements to model: Depuration



Courtesy of Marc Metian, IAEA Research Scientist

Depuration phase



For depuration - the initial point is
the cpm at the end of the uptake phase = 100%

% remaining activity:

$$\frac{\textbf{activity in organism at time t (Bq) * 100}}{\textbf{activity in organism at time 0 (Bq)}}$$

Courtesy of Marc Metian, IAEA Research Scientist

Depuration phase: kinetic parameters (k_e)

Remaining activities are plotted against time and loss kinetics are described by a one component exponential model

- $A_t = A_{0s} * e^{-ke*t}$

or double- component exponential model

- $A_t = A_{0s} * e^{-kes*t} + A_{0l} * e^{-kel*t}$

A_t : remaining activities at time t (%)

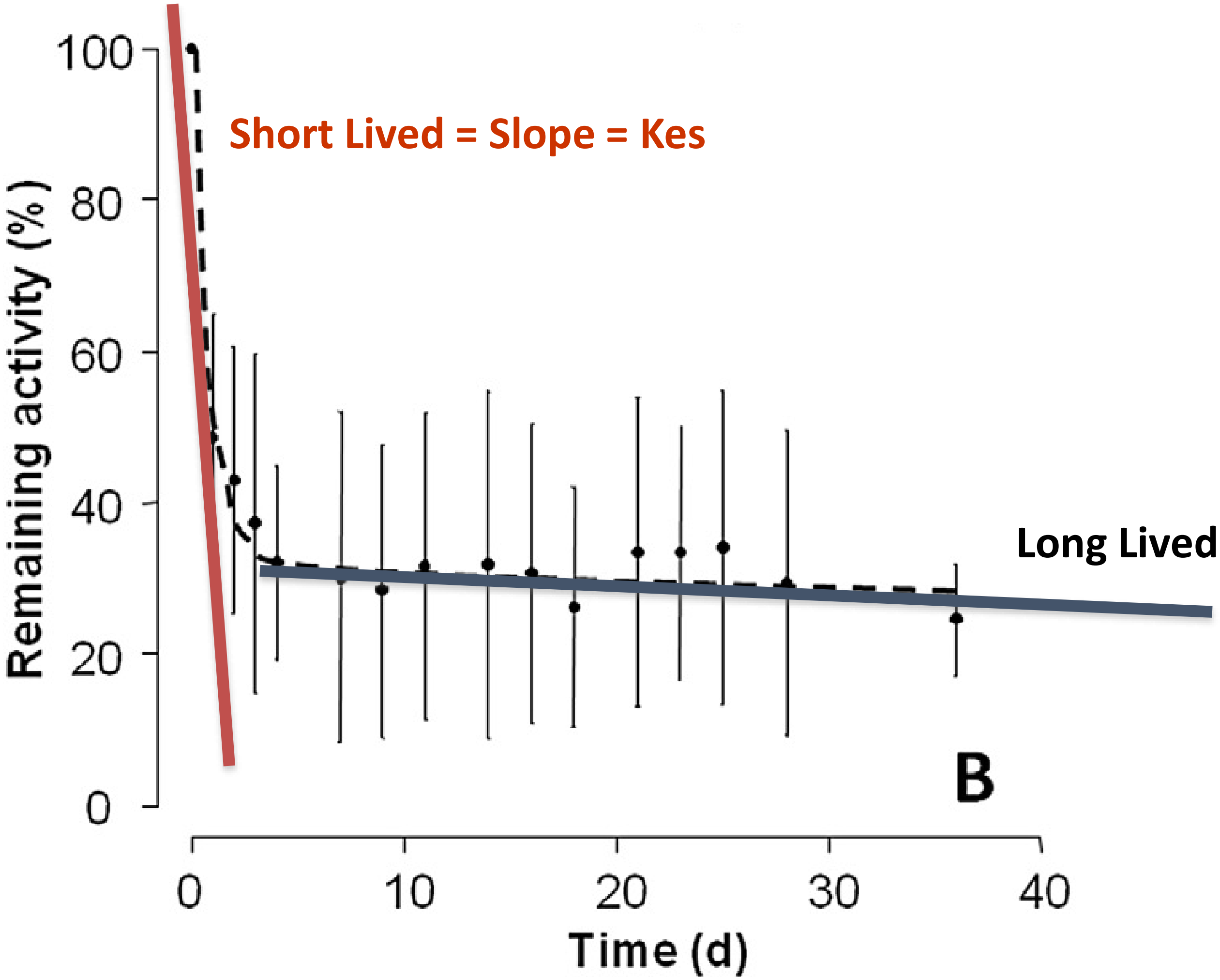
A_0 : remaining activities at time t (%)

K_e : loss rate constant (d^{-1})

*’**s**’ and ‘**l**’ are the subscripts for ‘short-lived’ and ‘long-lived’ components.*

Courtesy of Marc Metian, IAEA Research Scientist

Depuration phase: kinetic parameters



Short Lived = Slope = Kes

Long Lived = Slope = Kel

Biological meaning > ‘short-lived’ = Not retained by the organisms
‘long-lived’ = retained/detoxified/stored

Courtesy of Marc Metian, IAEA Research Scientist

Biological half-life: elimination by biological processes

One component

- $A_t = A_{0s} * e^{-\mathbf{ke}*t}$

Two components

- $A_t = A_{0s} * e^{-\mathbf{kes}*t} + A_{0l} * e^{-\mathbf{kel}*t}$

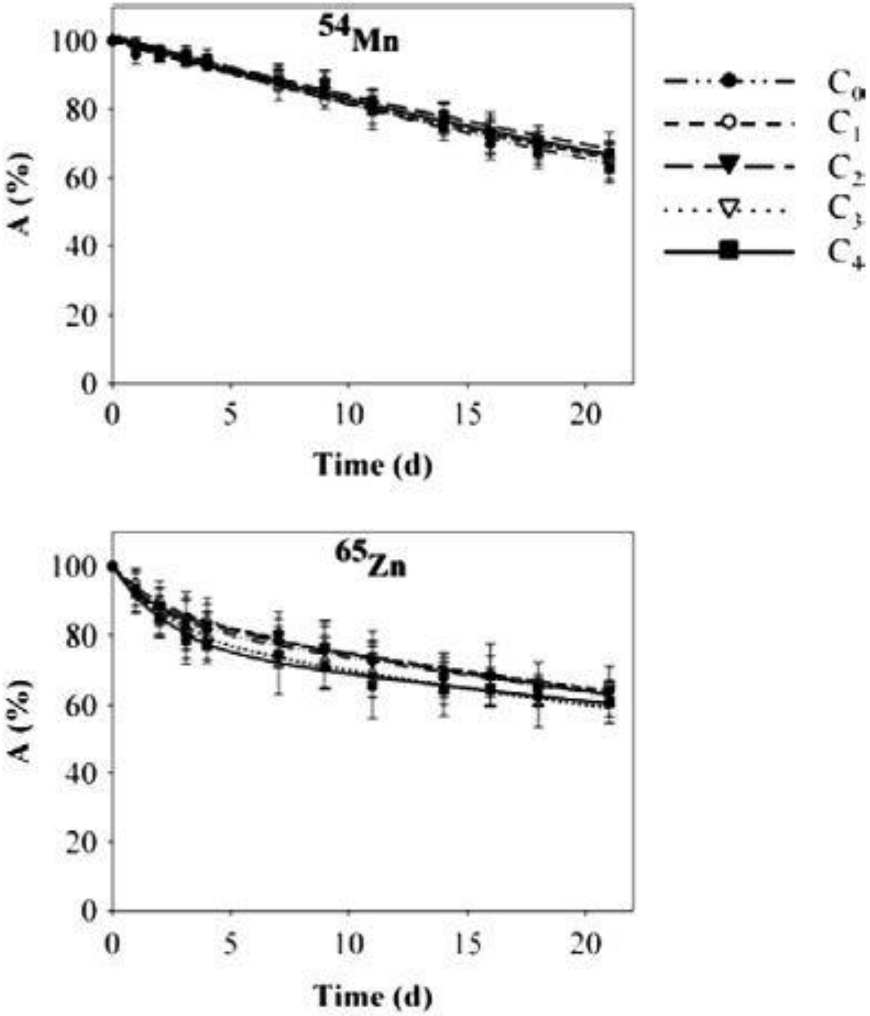
For each exponential component (s and l), **a biological half-life** can be calculated ($Tb_{1/2s}$ & $Tb_{1/2l}$) from the corresponding depuration rate constants (k_{es} & k_{el}) according to:

$$\mathbf{T_{b1/2} = ln2/k_e}$$

Courtesy of Marc Metian, IAEA Research Scientist

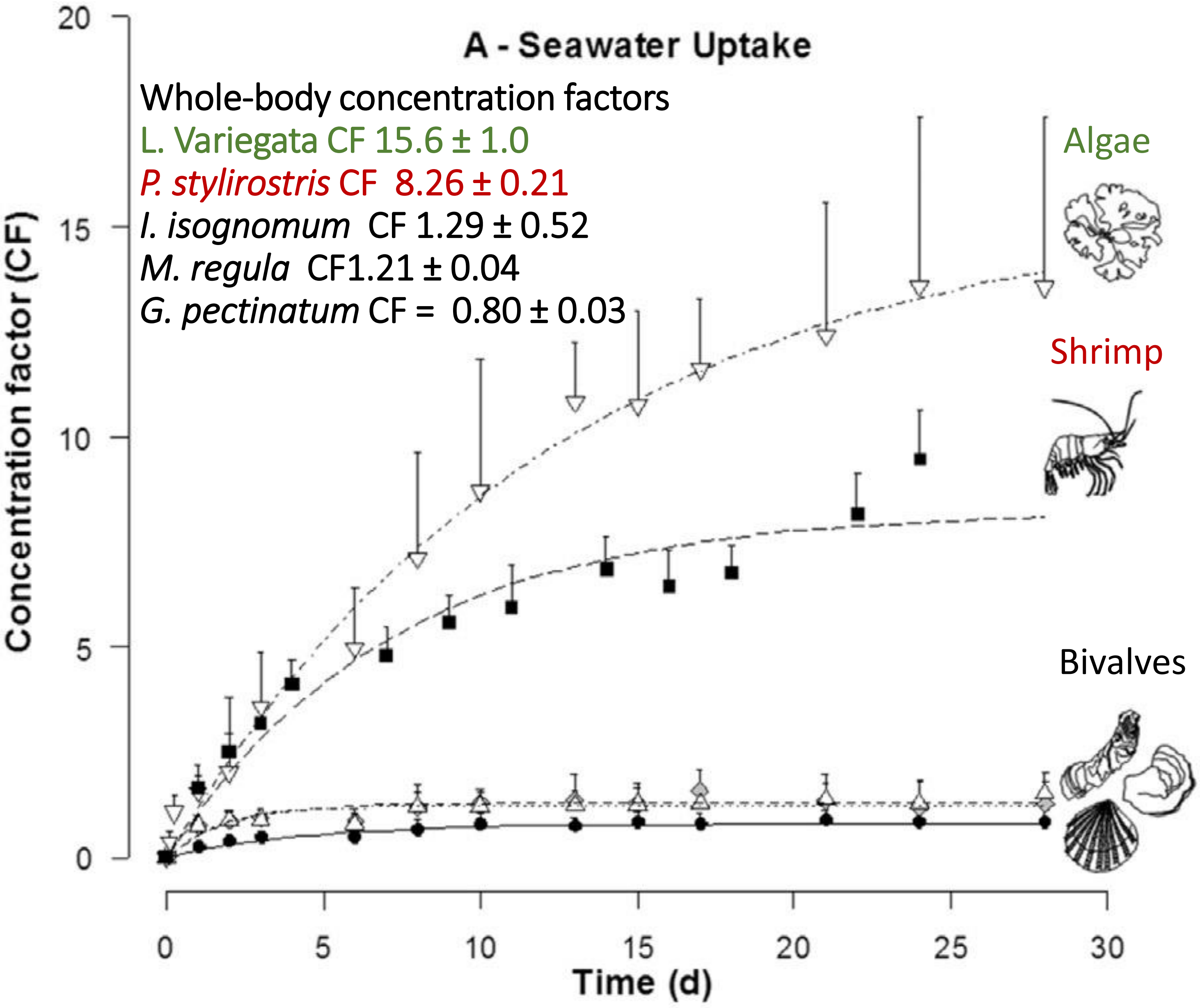
Example: Depuration phase: kinetic parameters

Example of one or double component models



Courtesy of Marc Metian, IAEA Research Scientist

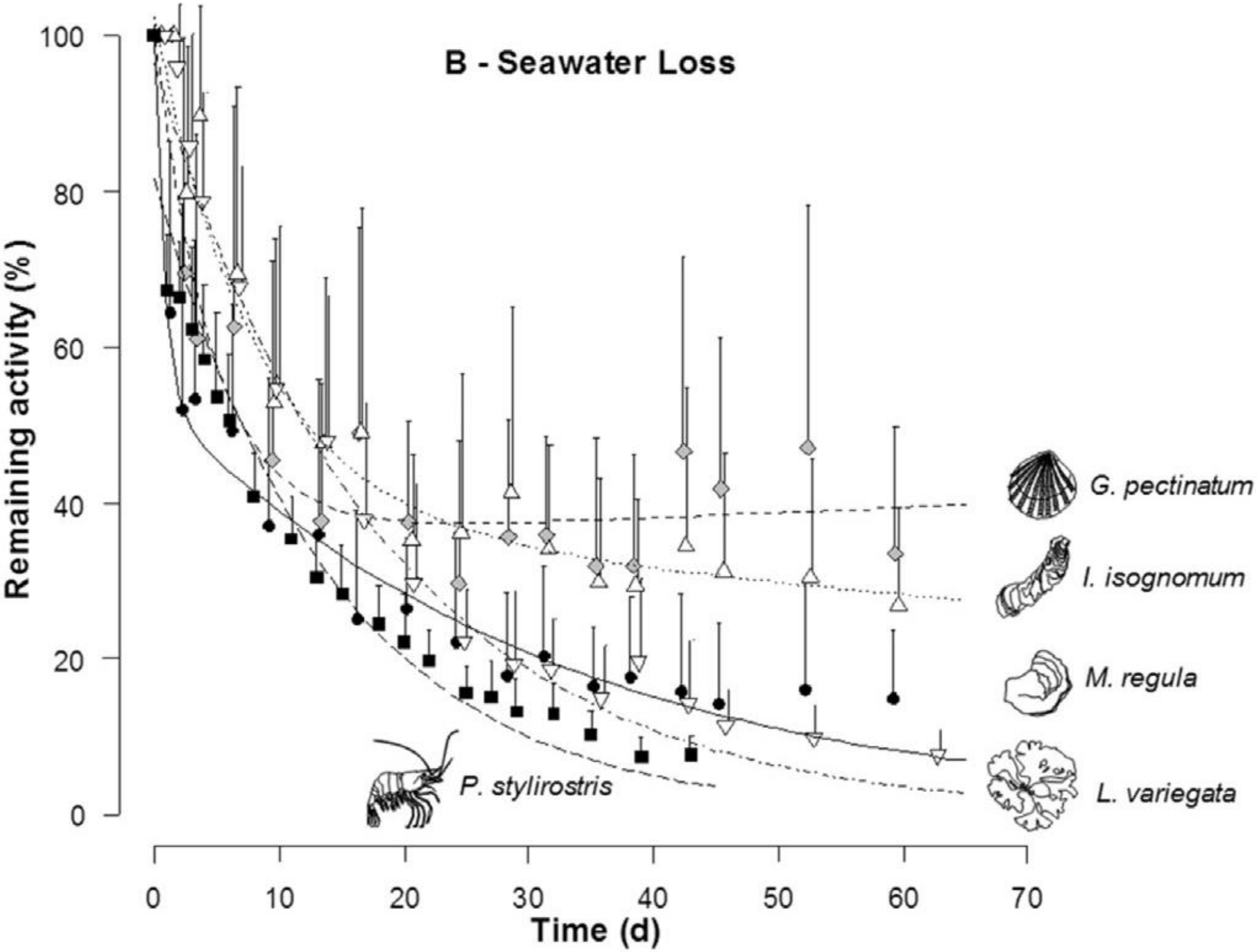
Example: Uptake kinetics of dissolved Cs during 24-28 days of exposure



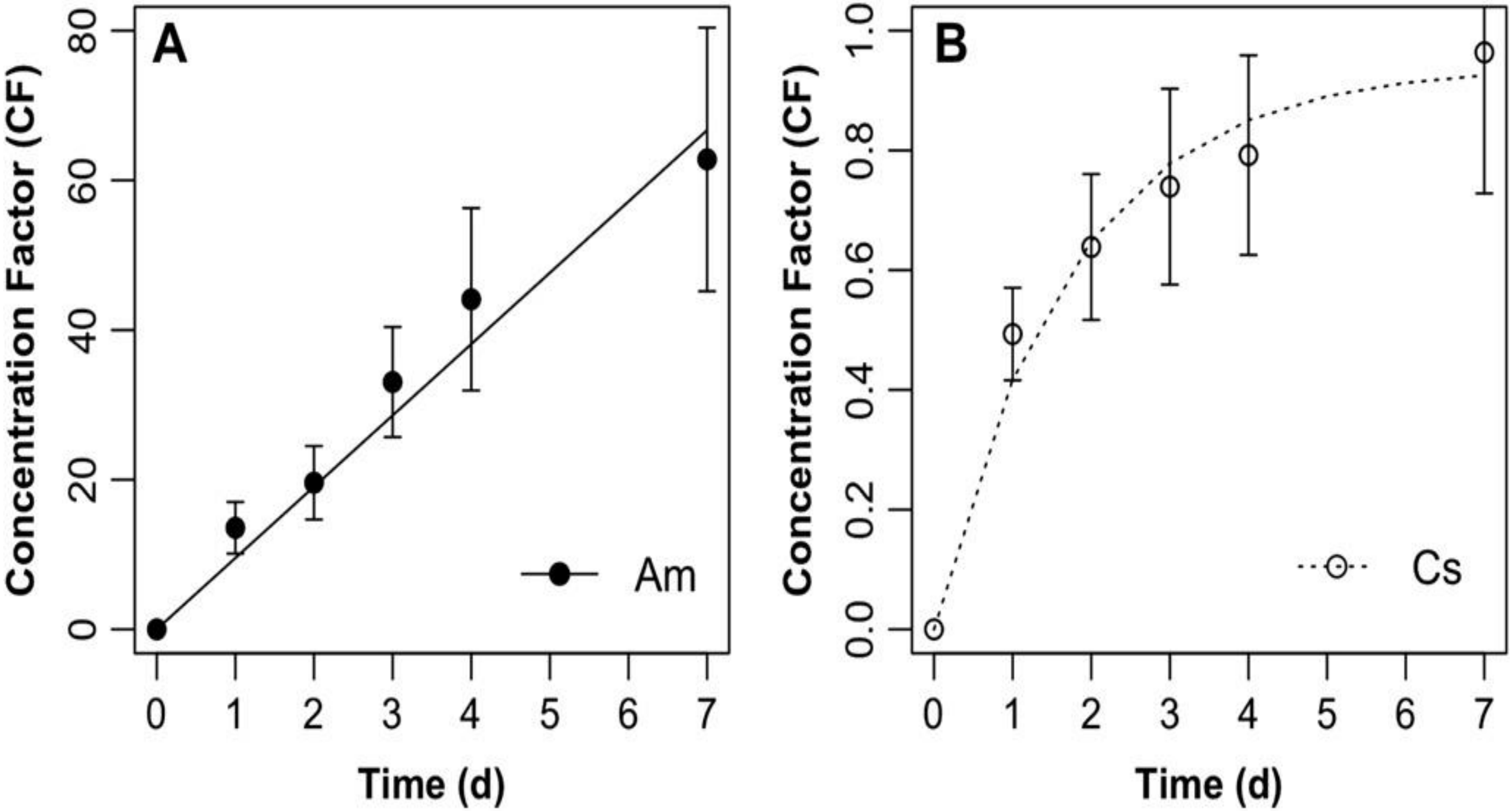
Whole-body concentration factors
L. Variegata CF 15.6 ± 1.0
P. stylirostris CF 8.26 ± 0.21
I. isognomum CF 1.29 ± 0.52
M. regula CF1.21 ± 0.04
G. pectinatum CF = 0.80 ± 0.03

Metian et al., JER, 2016

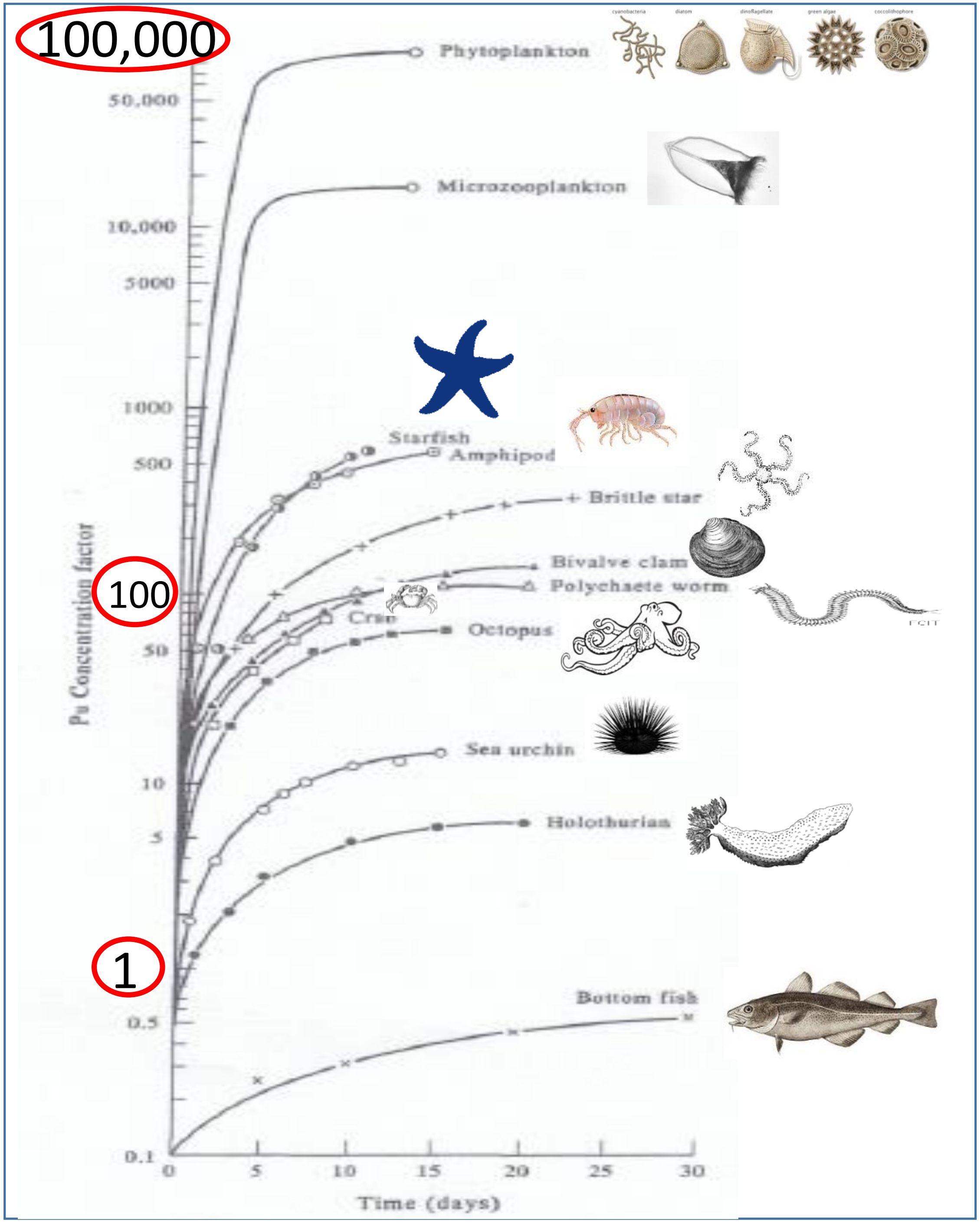
Example: Cs depuration kinetics when maintained for 43 to 62 d thereafter in clean seawater



Metian et al., JER, 2016



Uptake of ^{241}Am and ^{134}Cs from sea water by the scallop, Pecten maximus (n=9). From Metian et al. 2011



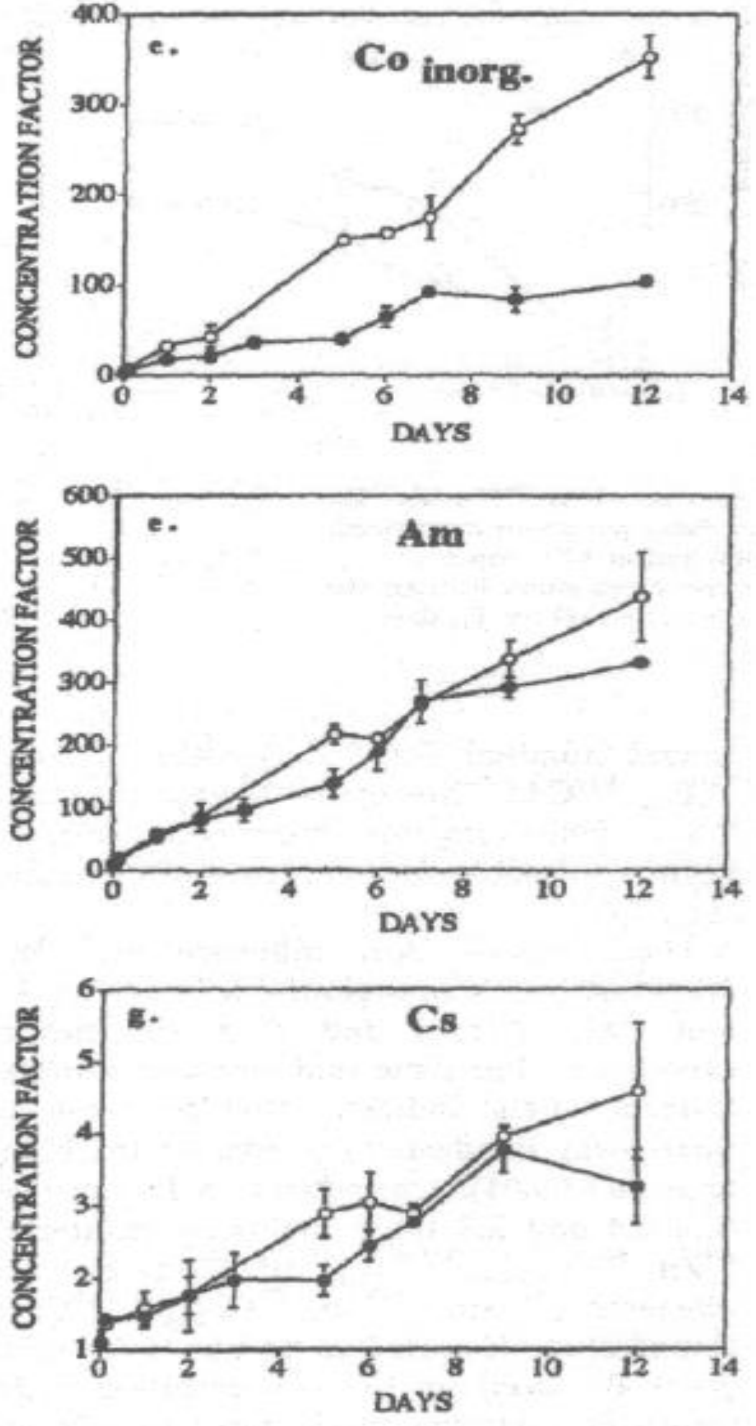
Species dependent Bioaccumulation of plutonium from seawater by various marine organisms

Fowler (1983)

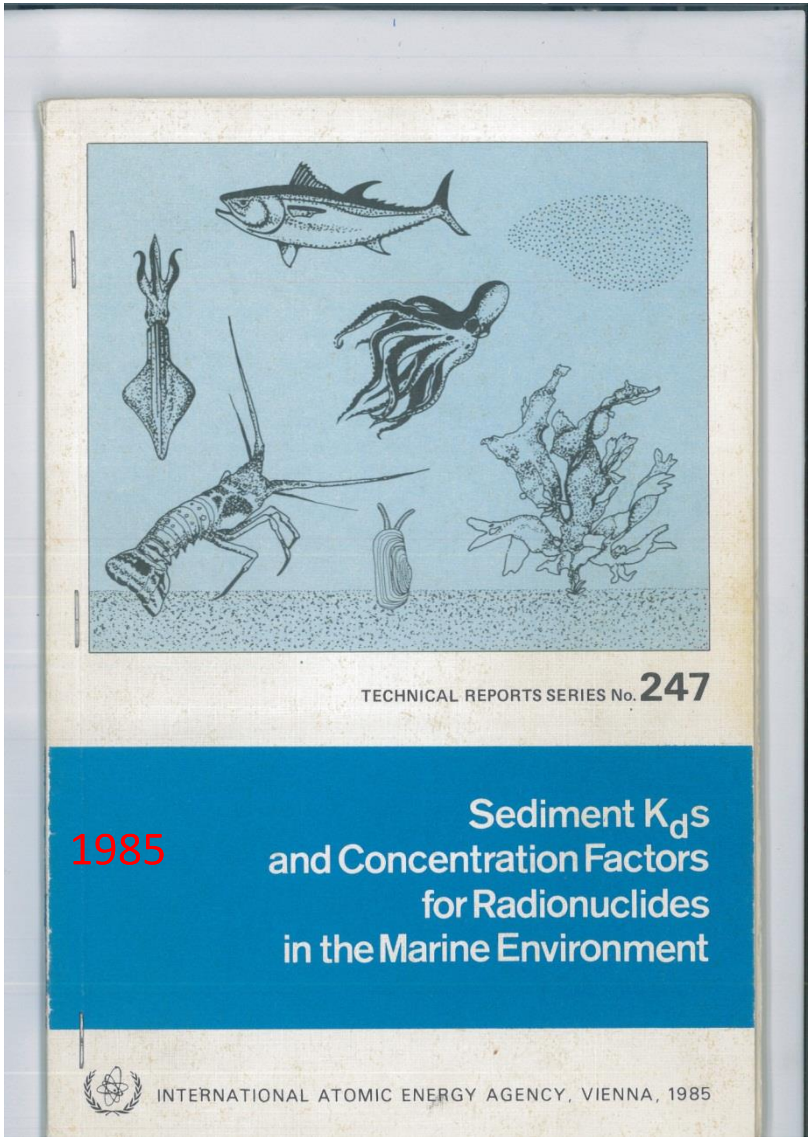
Effect of Temperature on Uptake of ^{60}Co, ^{241}Am and ^{134}Cs from Water by Brown Macroalgae (*Fucus vesiculosus*)

12 °C (○)

2 °C (●)



For more Information: See compilations



TECHNICAL REPORTS SERIES No. 247

Sediment K_ds
and Concentration Factors
for Radionuclides
in the Marine Environment

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1985

1985

TECHNICAL REPORTS SERIES NO. 422

Sediment Distribution
Coefficients and
Concentration Factors
for Biota in the
Marine Environment

2004

IAEA
International Atomic Energy Agency

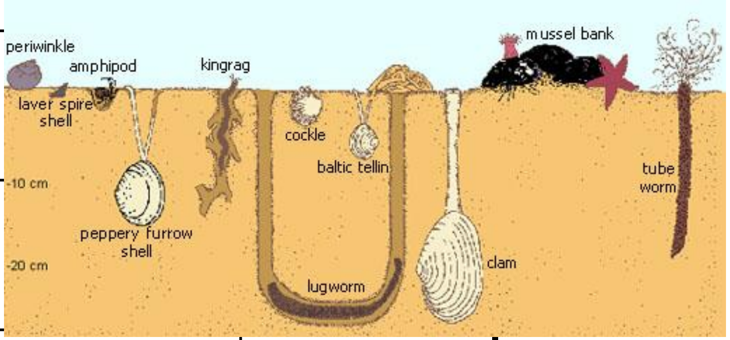
Concentration Factors and Assimilation efficiencies* of selected radionuclides in different taxonomic groups

Organism	^{137}**Cs**	$^{239+240}$**Pu**	^{241}**Am**	^{210}**Po**
Macroalgae	**50**	**4 000**	**8 000**	**1 000**
Phytoplankton	**20**	**200 000**	**200 000**	**70 000**
Zooplankton	**40** -	**4000** 0.8 - 1	**4000** 0.9 - 10	**30 000** 20 - 55
Decapod crustaceans	**50** -	**200** 10 - 60	**400** 8 - 58	**20 000** 35
Molluscs	**60** 3 - 4	**300** 0.9	**1 000** 0.6 - 38	**20 000** 17
Cephalopods	**9** 23 - 29	**50** -	**100** 51 - 60	**20 000** -
Teleost fish	**100** 42 - 95	**100** 0.1 - 1	**100** 0.7 - 6	**2 000** 5

* AE=*The fraction of ingested food that is absorbed and used in metabolism*

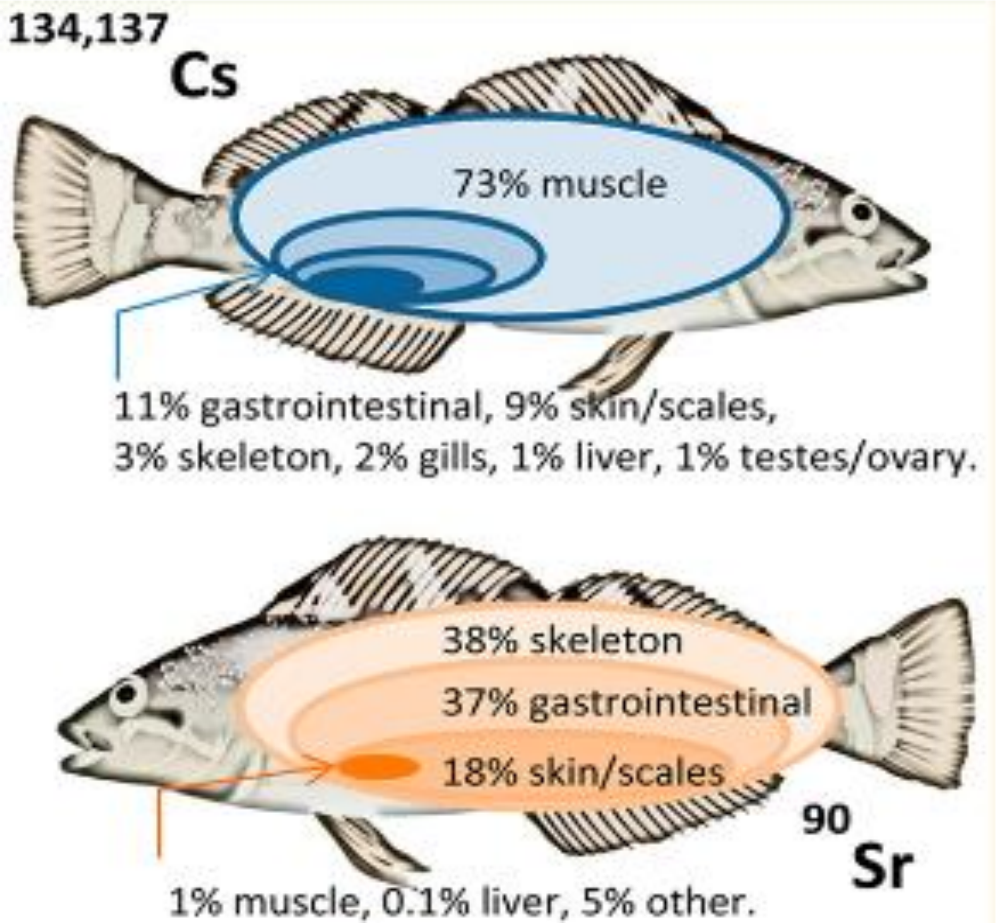
Transfer factors* of radionuclides accumulated from contaminated sediments

Organism	Uptake (days)	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{60}Co
Worms Nereis	11-50	0.0016	0.0009	0.2	0.06
Arenicola	14	0.002	0.003		
Clams Venerupis	40-50	0.006	0.004-0.02		
Scrobicularia	14	0.01	0.008		
Isopod Cirolana	40-50		0.006-0.032		
Amphipod Corophium	14	0.10	0.11		



* Transfer factor = Bq g^{-1} organism wet weight / Bq g^{-1} wet sediment

Distribution of ^{134,137}Cs and ^{90}Sr in fish tissues



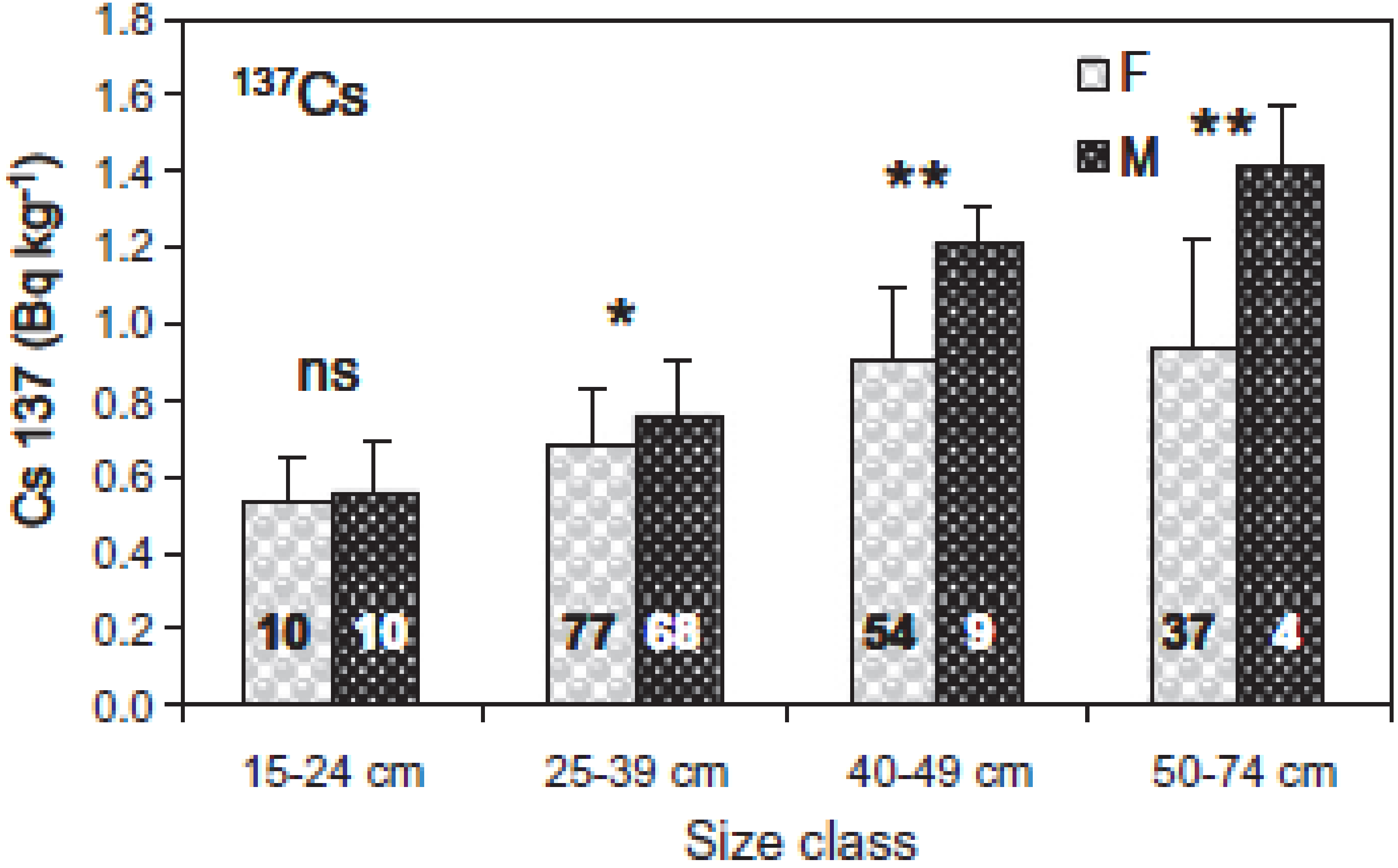
^{137}Cs is analog to ^{40}K

^{90}Sr is analog to Ca

2 years after the Fukoshima accident

Johansen et al., EST, 2015

^{137}Cs activities (dry weight) in different *size classes* of *male and female* European Hake



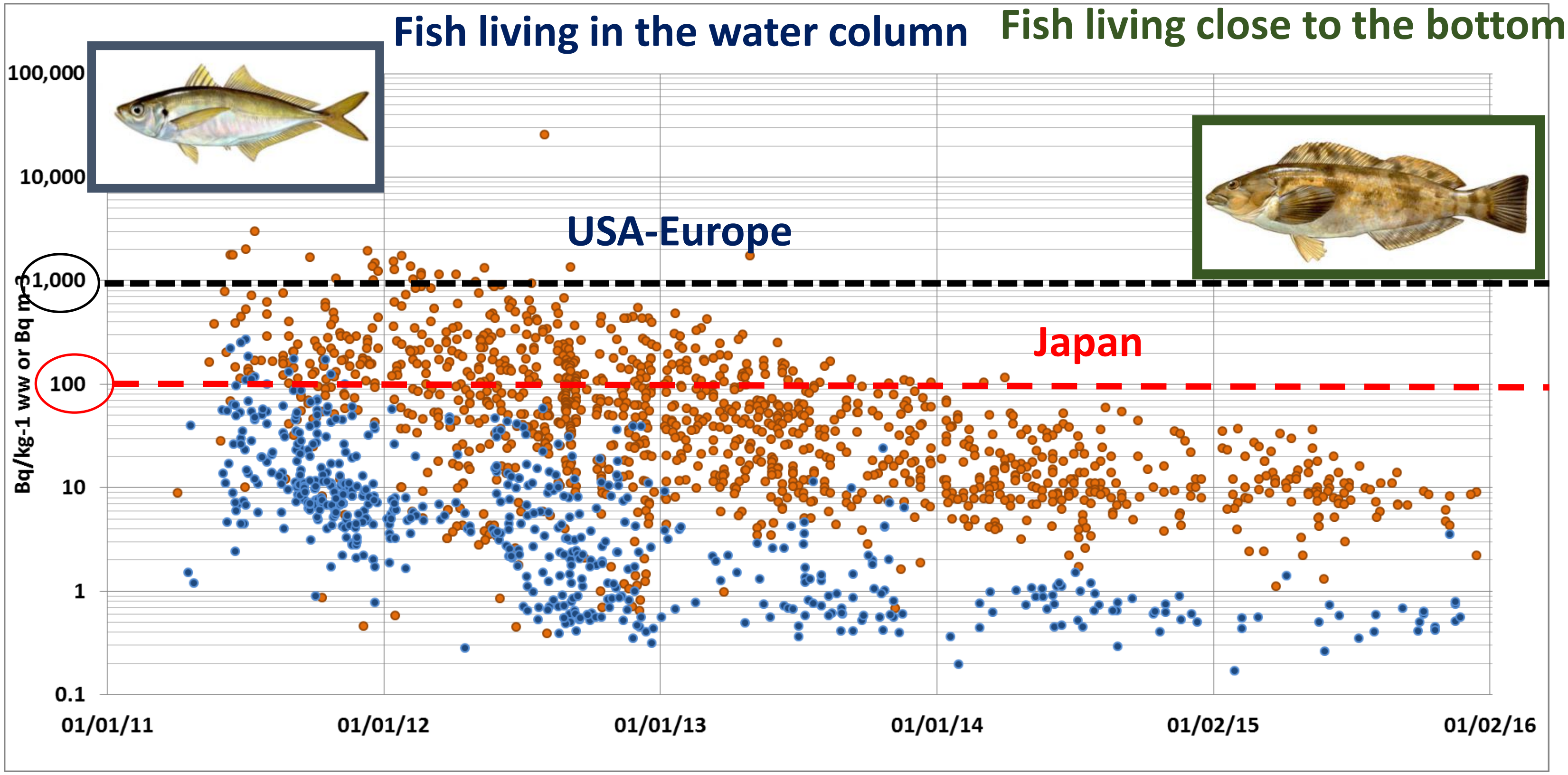
Numbers in bars = no. of individuals analyzed.
Significance of male-female difference: ns = not significant, * = $p < 0.05$, ** = $p < 0.01$

Harmelin-Vivien et al. 2012

Survey in an accidental case : The Fukushima Dai-ichi Nuclear Power Plant

Example : radiocesium in fish from the Fukushima prefecture

regulatory limit

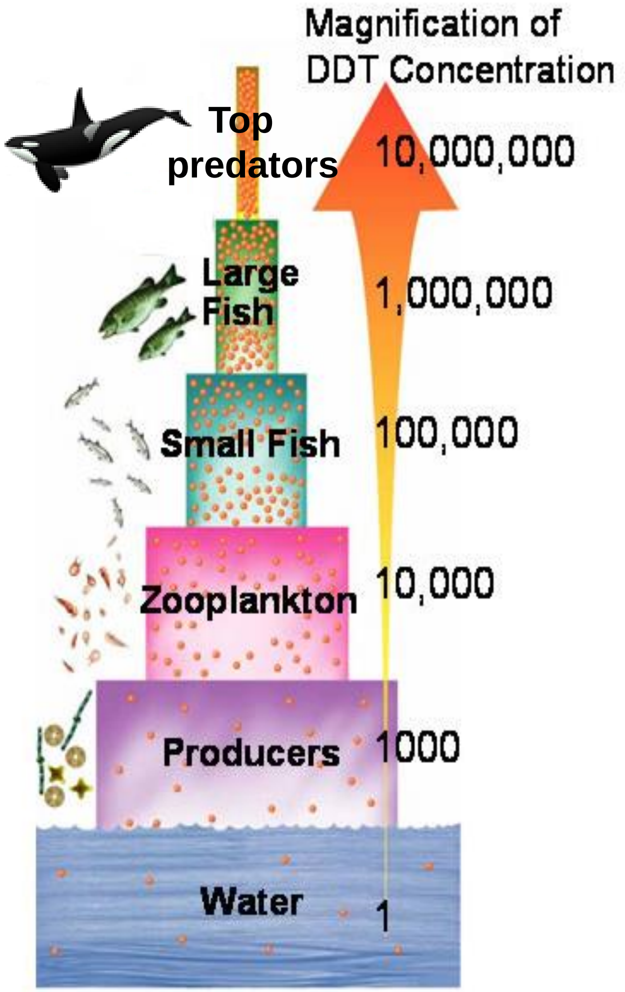


Do radionuclides biomagnify in marine food chains ?

Biomagnification = concentration of a substance increasing in the organisms at successively higher levels in a food chain

A limited number of substances do magnify in marine food chains, the most ‘famous’ ones being mercury, PCB or DDT.

Regarding radionuclides cesium is one which demonstrates a limited biomagnification.



^{137}Cs

300

150

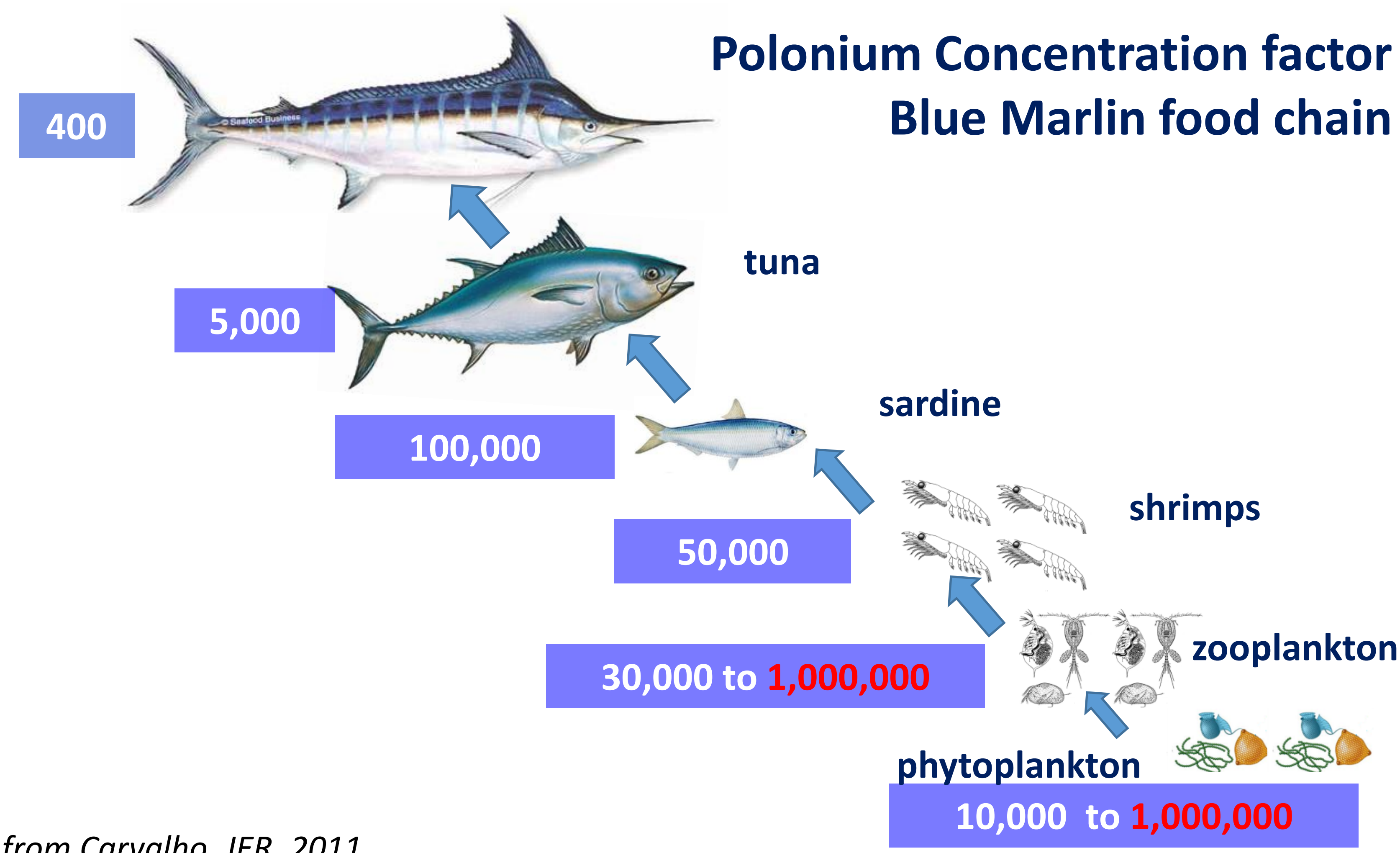
80

40

20

1

Po (highly toxic natural radionuclide) in marine food chains
Example of an element with **no biomagnification**



Polonium Concentration factor
Blue Marlin food chain

Data from Carvalho, JER, 2011

Environmental monitoring

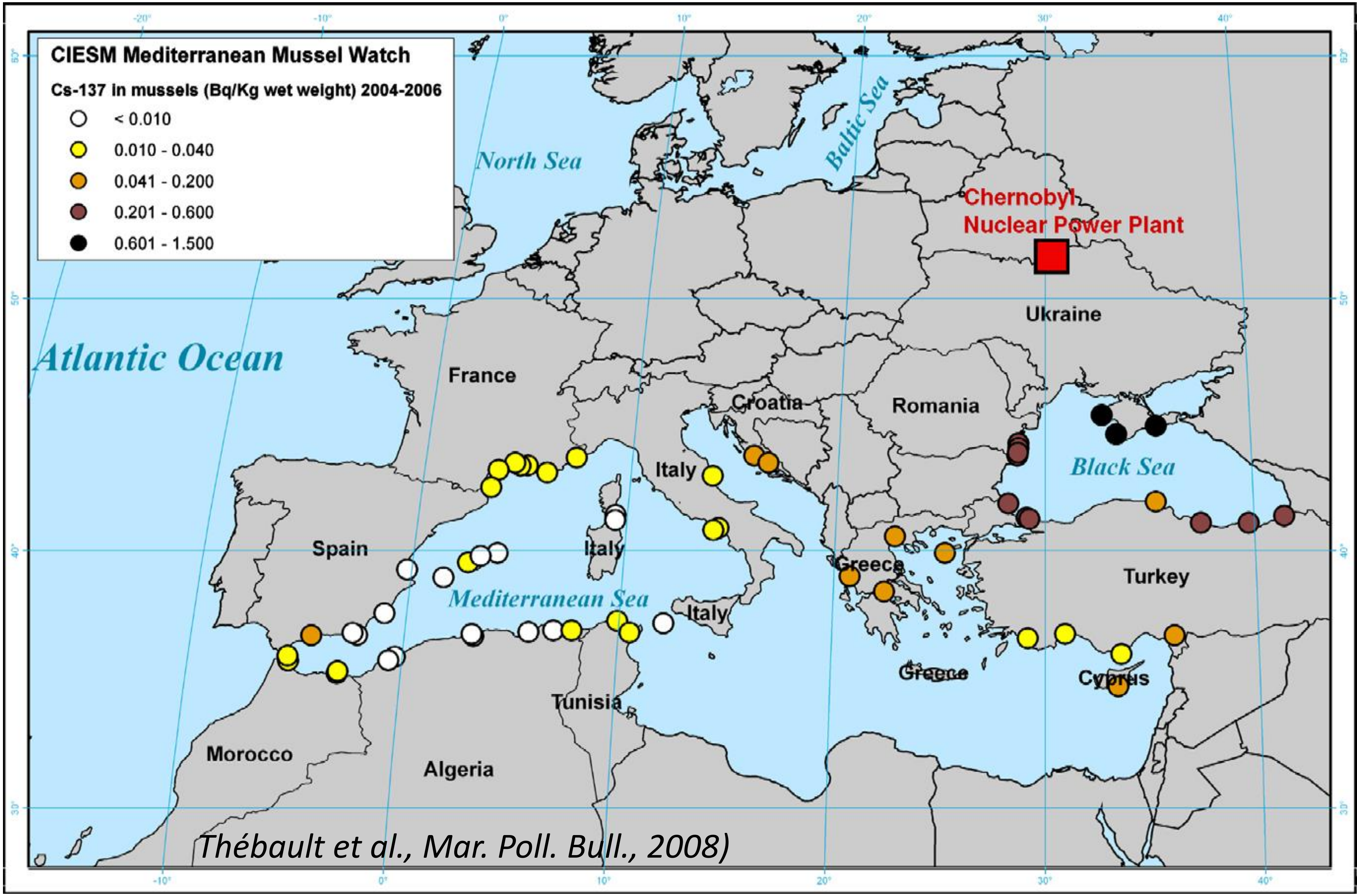
Bioindicators (monitors)

Organisms that can be used to determine the concentration of a chemical in the environment and has both large geographic and permanent distributions.

Mollusc : Mytilus

Algae : Fucus

MEDITERRANEAN MUSSEL WATCH



Thébault et al., Mar. Poll. Bull., 2008)

IV. What about the Radioprotection of the Environment? Ecological risk assessment and management

Radiological protection and the environment
Changing perspectives from anthropocentric to ecocentric

"Although the principal objective of radiation protection is the achievement and maintenance of appropriately safe conditions for activities involving human exposure, the level of safety required for the protection of all human individuals is thought likely to be adequate to protect other species, although not necessarily individual members of those species The Commission therefore believes that if man is adequately protected *then other living things are also likely to be sufficiently protected."* (ICRP, 1977)

"The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species." ICRP Publication 60 (1991)

It has been shown that practices such as disposal of radioactive waste into the deep sea (i.e., remote areas) could, in theory, deliver very high dose rates to the benthic fauna whilst maintaining dose rates to man well below the dose limits for human exposure currently recommanded by the ICRP (Pentreath, 1998).

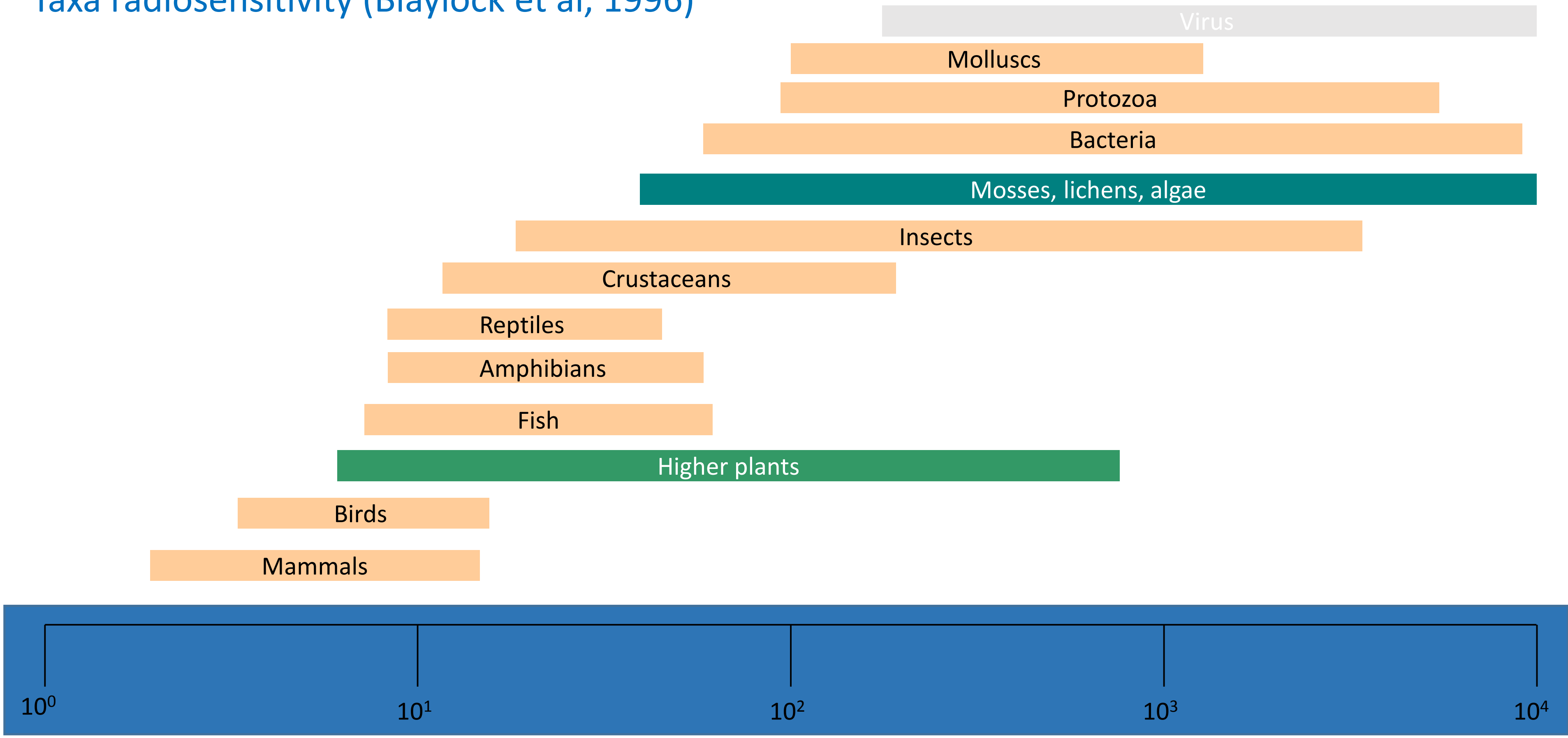
Also increasing regulatory weight for the protection of the environment

So Radioprotection pay more attention on developping environmental criteria for biota

What we know regarding the effects on organisms:

Acute ionizing radiation exposures

Taxa radiosensitivity (Blaylock et al, 1996)

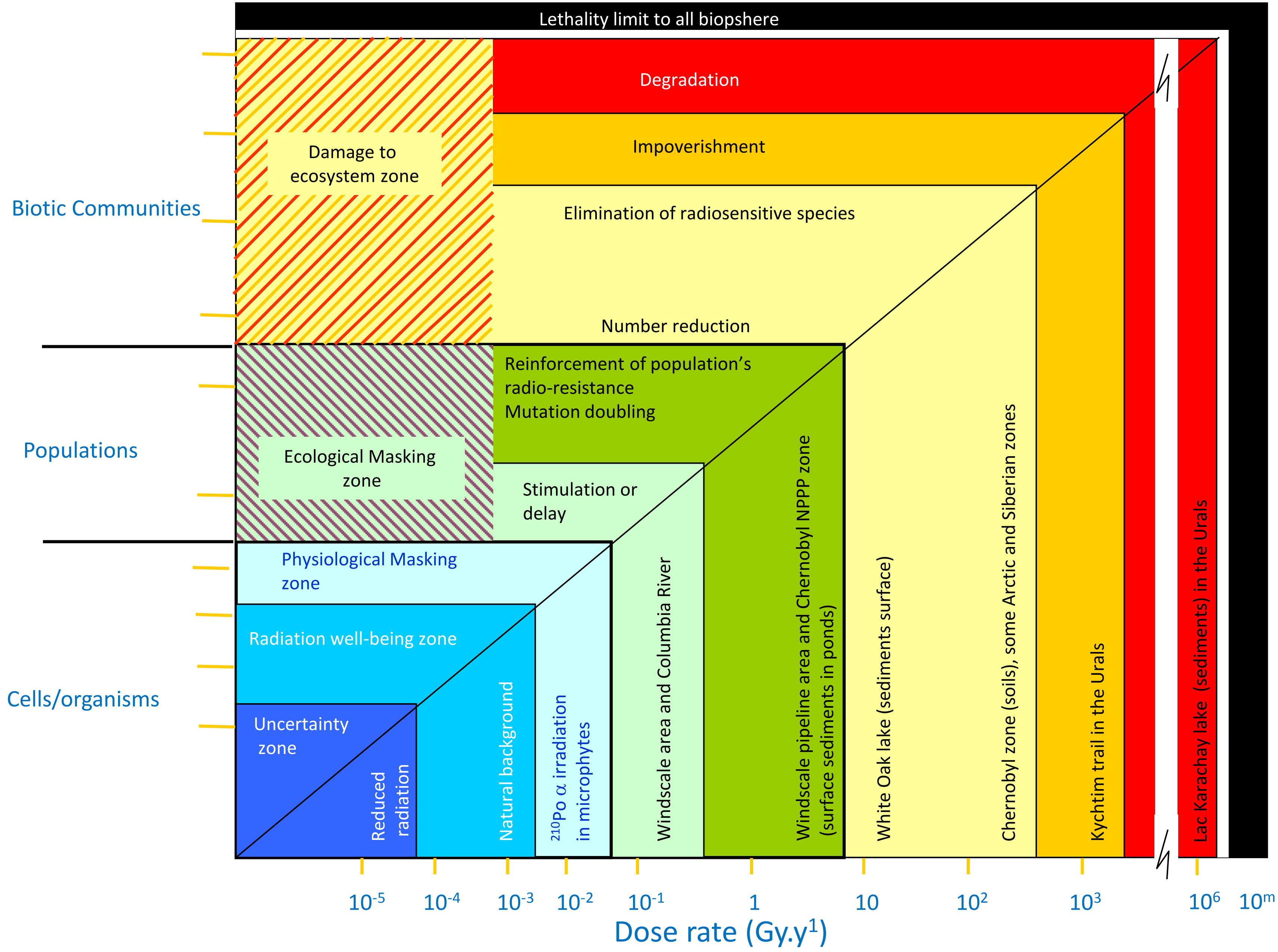


Acute lethal dose (Gy)

Credit K. Beaugelin-Sellier, IRSN

Chronic Exposure

Zones of dose rates and their effects to the biosphere (Polikarpov, Radiat. Protec. Dos., 1998)



Lethality limit to all biopshere

Degradation

Impoverishment

Elimination of radiosensitive species

Number reduction

Damage to ecosystem zone

Reinforcement of population’s radio-resistance
Mutation doubling

Stimulation or delay

Ecological Masking zone

Physiological Masking zone

Radiation well-being zone

Uncertainty zone

Biotic Communities

Populations

Cells/organisms

The ERICA tool, the 1st European answer towards demonstration of environmental protection

- The outcome of a suite of european research programmes:

  2004-2007 (first release) ERICA: Environmental Risk from Ionising Contaminants: Assessment and Management

  - A free software that has a structure based upon a tiered Integrated Approach to assessing the radiological risk to terrestrial, freshwater and marine **biota**
  - A tool based on a reference organism approach based **on biological effects on individual marine biota**
  - Updated in 2008, 2009, 2011, 2012, 2014 and 2016.
  - Website : www.erica-project.org

The ERICA tool: Based on reference organisms

> *“a series of entities that provide a basis for the estimation of radiation dose rate. These estimates, in turn, provide the basis for assessing the likelihood and degree of radiation effects to a range of organisms which are typical, or representative of a contaminated environment.”*

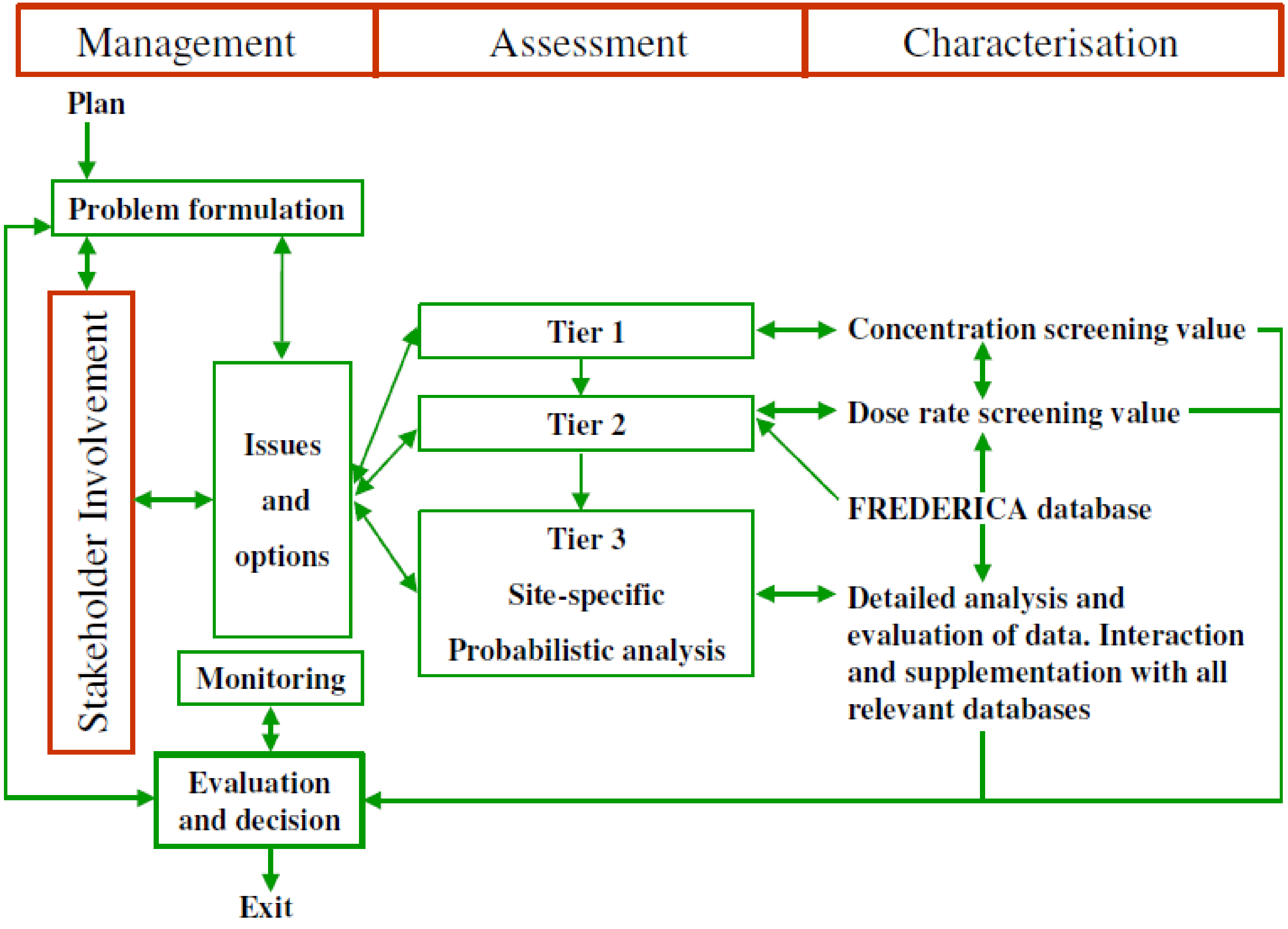
- Radiosensitivity,
- Ecological sensitivity,
- Ecological significance

Reference organisms
Phytoplankton
Brown algae
Vascular plant
Zooplankton
Polychaete worm
Bentgic mollusc
Crab
Flat fish
Pelagic fish
Duck
Mammal
Turtle
Sea anemones & True corals

Suggested screening benchmark: 10 µGy h^{-1}

to protect the structure and functions of a generic ecosystem

The ERICA tool: An iterative process



Inappropriate/incomplete conceptual models (methodology mismatched with objectives)

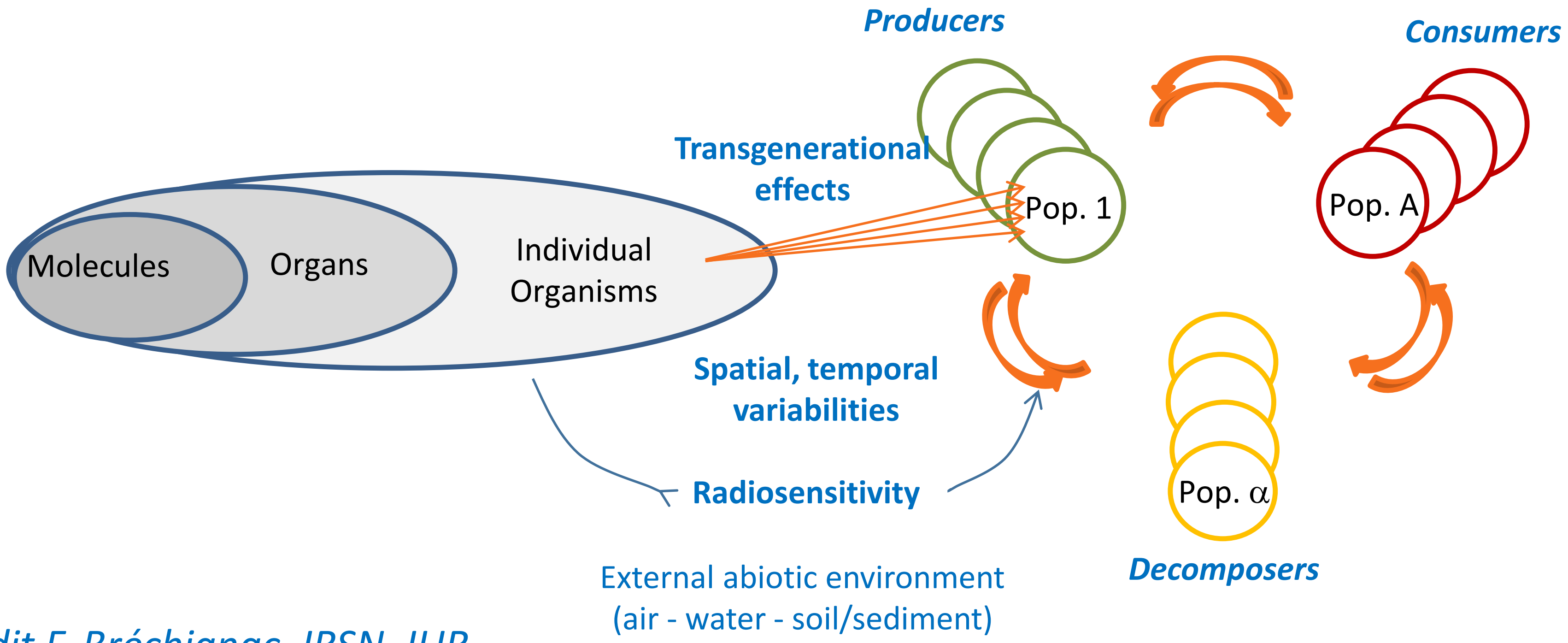
Biological impact of radiation
(RAPs, ICRP)

Endpoints:
- Mortality
- Morbidity
- Reproductive success
- Mutations

Objectives of protection are here

Ecological impact of radiation
(Ecosystem approach, IUR-CERAD)

Possible endpoints:
- Population attributes
- Biodiversity index
- Trophic network structure, …



Producers

Consumers

Transgenerational effects

Molecules

Organs

Individual Organisms

Pop. 1

Pop. A

Pop. α

Spatial, temporal variabilities

Radiosensitivity

Decomposers

External abiotic environment
(air - water - soil/sediment)

Credit F. Bréchignac, IRSN, IUR

^{210}Po

In summary

^{137}Cs

Worldwilde : A large variety of radionuclides coming from various sources (natural, man-made)

^{14}C

^{90}Sr

They are bioaccumulated by marine organisms

BUT Bioaccumulation depends on :

^{238}Pu

- **the marine organism**
- **the radionuclide**
- environmental parameters (temperature, salinity..)

SO IT IS COMPLEX….

Dose to man and biota mainly arise from natural sources