MASTER CBRNe
Chemical, Biological, Radiological, Nuclear and explosive
Department of Industrial Engineering and School of Medicine and Surgery

Decision Support Systems

Tools to support decision making for Radiological events

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Outline of the Lecture

- *Introduction, simple radiological scenarios, advantages of DSS.*
- *HotSpot: introduction and use of the code.*
- *HotSpot: a case study.*
- *HotSpot: practical exercises.*

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Decision Support Systems

Introduction

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Introduction

A Decision Support System (DSS) is an interactive computer-based system or subsystem intended to help decision makers use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions.

Introduction

Decision Support System is a general term for any computer application that enhances a person or group's ability to make decisions.

Radiation Protection

In radiation protection, computer applications are commonly used is a large variety of situations:

- dose evaluation;
- contamination assessment;
- shielding design;
- waste management.

Radiation Protection

In the present lecture, the focus is on a specific code: HOTSPOT.

However, before to start, it is important to underline the importance of computer applications through simple exposure scenarios and the steps needed in calculating the associated dose.

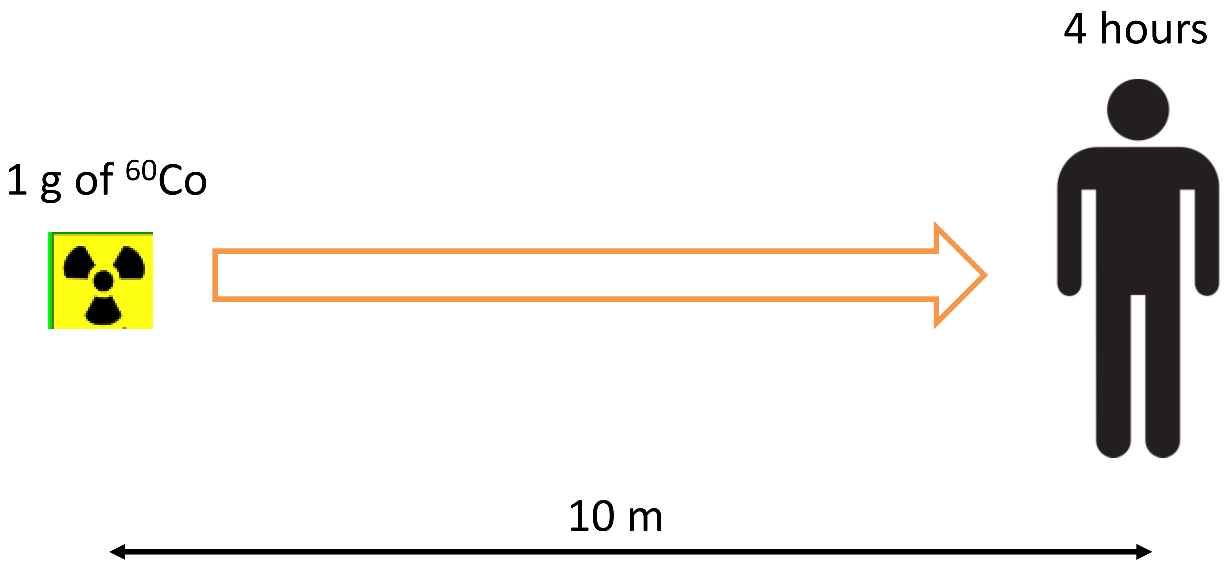
A practical problem

Consider 1 gram of ^{60}Co in metallic form and unshielded.

A person is working at a distance of 10 m, for 4 hours.

How to calculate the effective dose?

External exposure



Calculate the effective dose.

Effective dose

Effective dose is usually the quantity of interest when dealing with the biological effects of radiation.

It is designed as a measure of “radiation detriment” (cancer incidence, cancer mortality, life shortening and hereditary effects).

Limits and recommendations are often stated in terms of effective dose.

ICRP Recommendations

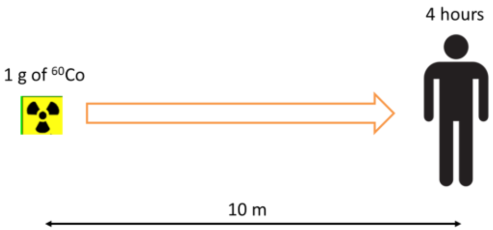
Proposed nominal risk coefficients (10^{-2} Sv^{-1}).

Exposed population	Cancer	Heritable effects	Total
Whole	5.5	0.2	5.7
Adult	4.1	0.1	4.2

Recommended dose limits (mSv y^{-1}).

	Occupational	Public
Effective dose	20	1

(adapted from ICRP 103)



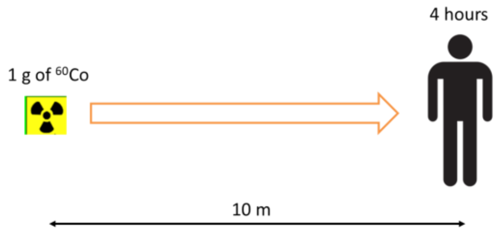
Step 1: from mass to activity

The mass number of ^{60}Co is 60. This means that in 60 g the number of atoms is equal to the Avogadro's number N_{Av}:

$$N_{Av} = 6.022 \times 10^{23}\ mol^{-1}$$

In 1 g of ^{60}Co the number of atoms is:

$$N = N_{Av} / 60 \approx 10^{22}$$



Step 1: from mass to activity

The activity is given by:

$$A = -dN/dt = \lambda N$$

where λ is the decay constant (s^{-1}). Numerically:

$$A = \lambda N = \frac{ln2}{T_{½}} N = \frac{0.693 \times 10^{22}}{5.3 \times 365 \times 24 \times 60 \times 60} = 4.2 \times 10^{13}\ Bq$$

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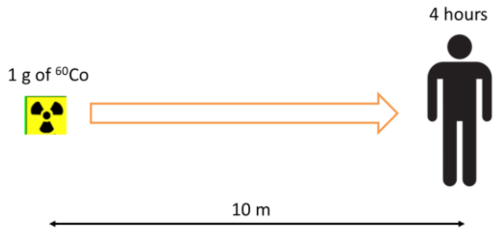
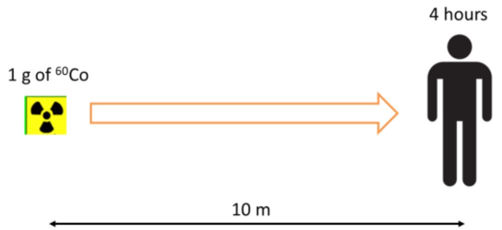


Step 2: from activity to dose

In order to calculate the effective dose, COEFFICIENTS are needed.
The GAMMA CONSTANT converts the activity into dose (per unit of distance and time of exposure).

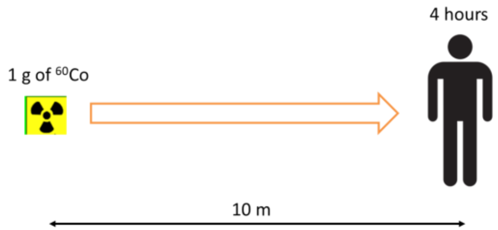
Note: several assumptions and clarifications are needed when calculating the effective dose.



Step 2: from activity to dose

$$E = \Gamma \frac{A}{d^2} \times t$$

E = effective dose (mSv)
Γ = specific gamma constant (mSv m^2 h^{-1} MBq^{-1})
A = activity (MBq)
d = distance (m)
t = time (h)



Step 2: from activity to dose

Specific gamma constants can be found in the scientific literature.

A good reference is: Delacroix D et al. *Radionuclide and radiation protection data handbook*. Radiat Prot Dosimetry 98: 9-168 (2002).

RADIONUCLIDE AND RADIATION PROTECTION DATA HANDBOOK 2002

D. Delacroix*
J. P. Guerre**
P. Leblanc**
C. Hickman

* Commissariat à l'Energie Atomique, CEA/DAM - Ile de France, France
**Commissariat à l'Energie Atomique, CEA/Saclay, France

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Extract for ^{60}Co

E3				
% omitted	< 1	0		

IAEA ST1 A_1 value	4E-1
IAEA ST1 A_2 value	4E-1

EXTERNAL EXPOSURE ($mSv.h^{-1}$) for an activity of 1 MBq or 1 $MBq.m^{-2}$ (as appropriate)

Point source (30 cm)

Betas, electrons (skin dose): 1.26E-2

Gammas, X rays (deep tissue dose): 3.86E-3

Infinite plane source

Betas, electrons (skin)	
10 cm	2.6E-02
1 m	0.0E+00

Photons (skin)	
10 cm	1.6E-02
1 m	1.0E-02

Photons (deep dose)	
10 cm	1.5E-02
1 m	9.6E-03

10 ml glass vial

100 cm: 3.32E-4

Contact with 50 ml glass beaker

1.19E+0

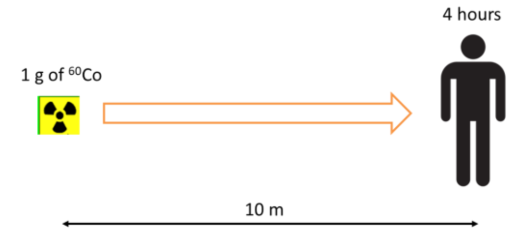
Contact with 5 ml plastic syringe

5.67E+0

The values above do not include Bremsstrahlung radiation.

CONTAMINATION		
		Derived limits

SHIELDING (mm)
Betas and electrons



Step 2: from activity to dose

Numerically,

$$E = \Gamma \frac{A}{d^2} \times t = \frac{3.86 \times 10^{-3} \times 4.2 \times 10^{7} \times 0.3^{2} \times 4}{10^{2}}$$

$$E = 580\, mSv$$

Important to learn

The previous example is a POINT SOURCE and the dose can be easily calculated. Radiation is uniformly emitted in all directions, so that the dose is inversely proportional to the square of the distance from the source:

$$D = k/d^2$$

D = dose; k = constant for a particular source; d = distance.

Important to learn

The dose from an external source depends on:

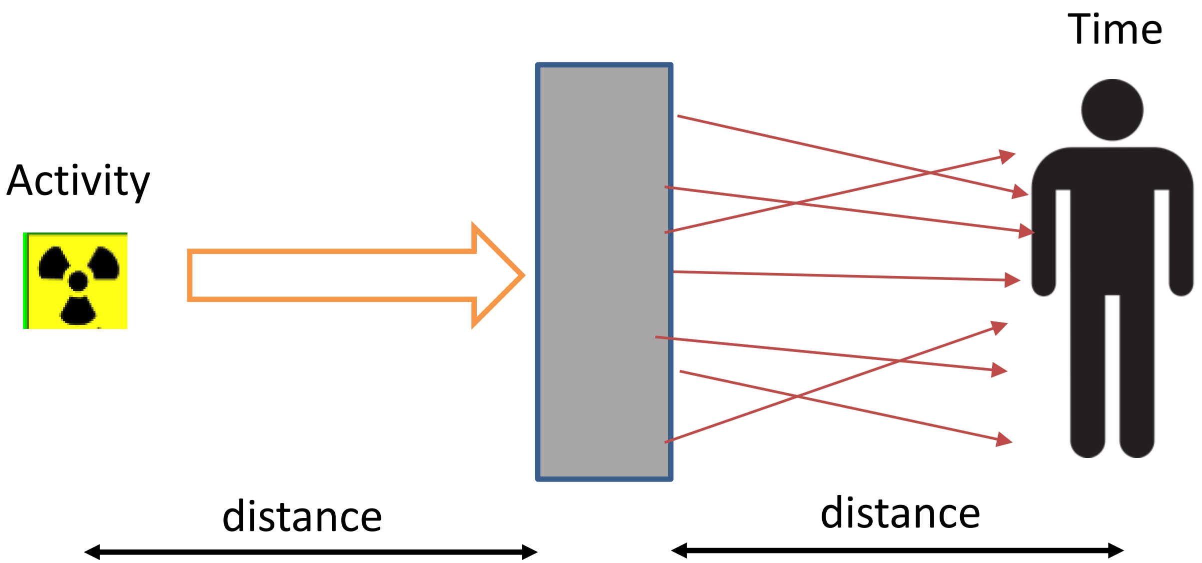
TIME

DISTANCE

SHIELDING

The presence of shielding makes the calculation more difficult, due to the scattered radiation.

External exposure



Shielding.

Advantages of computer codes

They automatically calculate values AND they often contain LIBRARY.

Constants and coefficients are “embedded” in the code: no need of external data.

Note: check if data are UP-TO-DATE.

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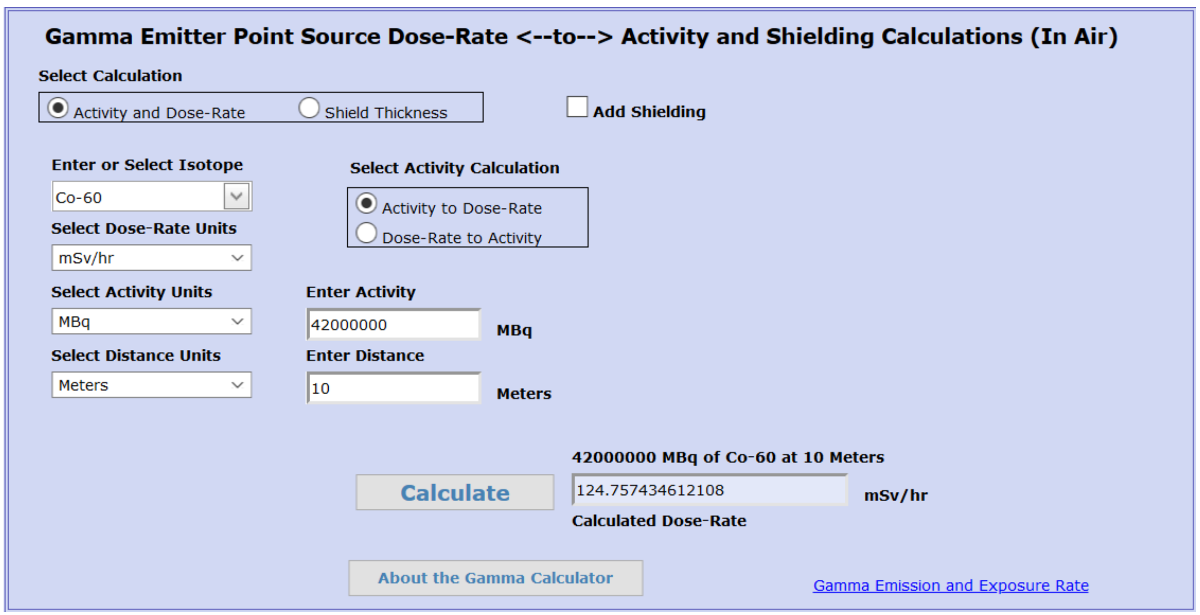
Example of computer codes

Rad Pro Calculator

http://www.radprocalculator.com/Gamma.aspx



Complexity

The evaluation of effective dose through the specific gamma constant is satisfactory in many cases.

It is valid for the dose in a point, but the human body is not.

Unfortunately, human exposure and contamination is often much more complex.

Dispersion of ^{239}Pu

For example, consider a fire involving a 1 g source of ^{239}Pu, but not all the Pu is released. A worker is contaminated, having inhaled only a tiny fraction of the released plutonium.

Dispersion of ^{239}Pu

Is the totality of ^{239}Pu dispersed in air?
What is the concentration of ^{239}Pu in air?
Is the concentration in air constant?
How much ^{239}Pu is inhaled?
Is the dose dependent on other factors?
Other?

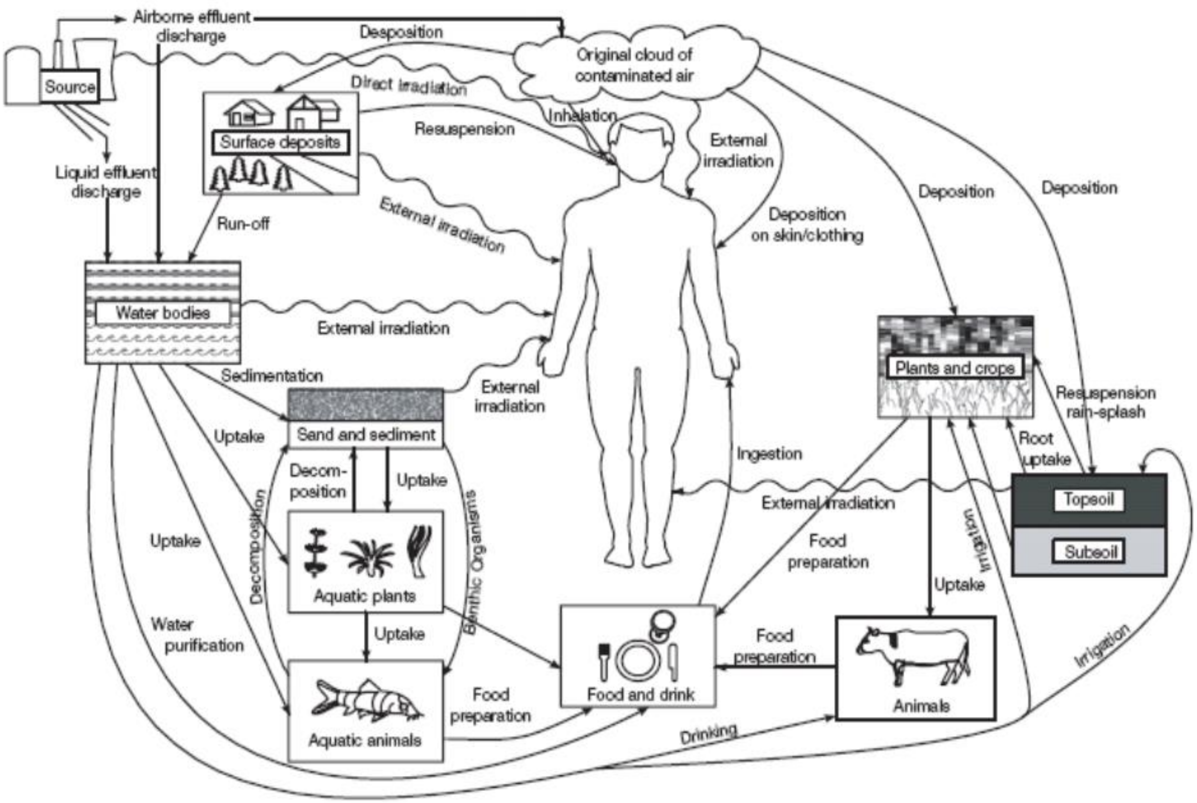
Dispersion of ^{239}Pu

Models are needed to take into account all the factors affecting the dose.

Other than automatically calculate values and having a library, COMPUTER APPLICATIONS use MODELS.

All the previous questions are taken into account by the model.

The full picture



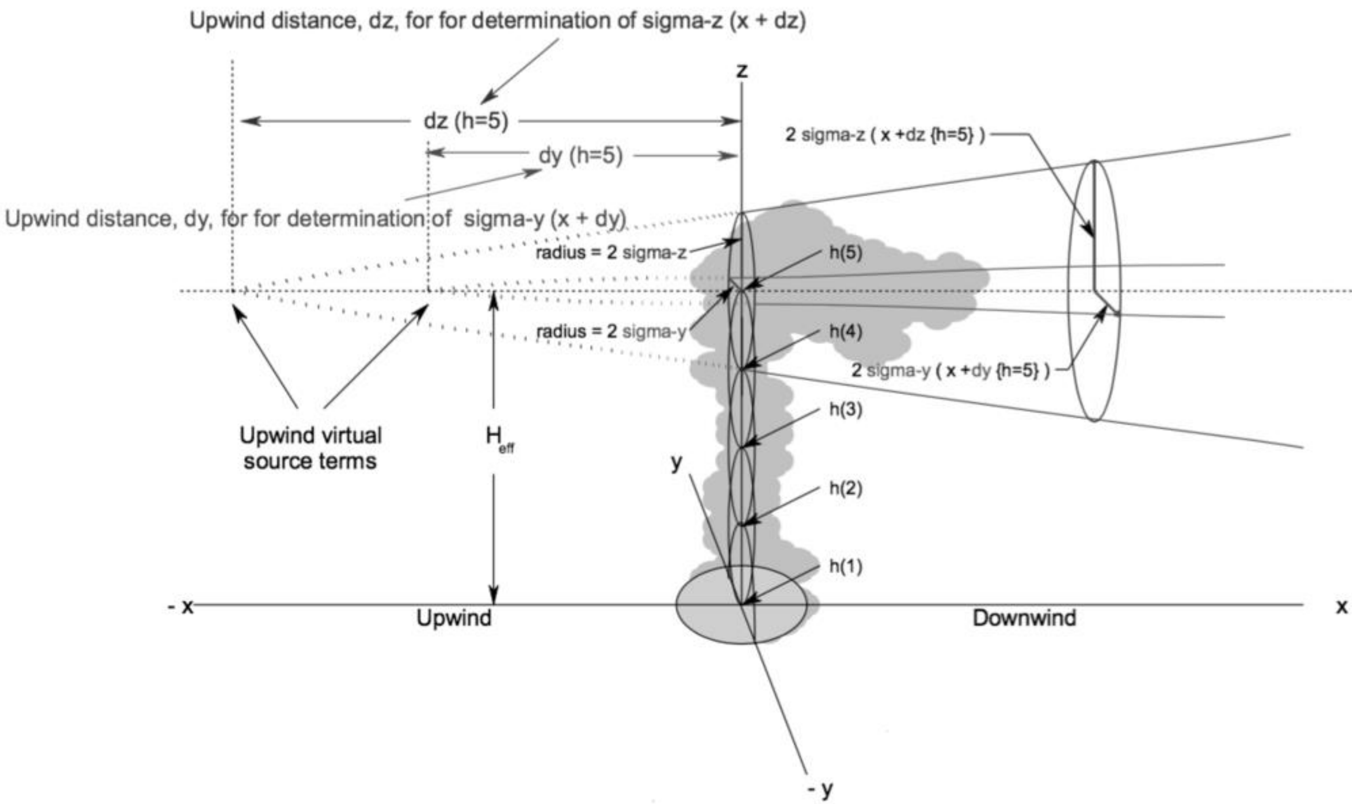
DSS (and models) are needed

To calculate the dispersion and distribution of radionuclides, the external exposure and to determine the intake*.

To describe the physical movement of radionuclides in the body following intake, and the deposition of energy that constitutes exposure (ICRP).

*ICRP defines intake as “Activity that enters the body through the respiratory tract or the gastrointestinal tract or the skin”.

Dispersion models



ICRP

The International Commission on Radiological Protection (ICRP) was established by the Second International Congress of Radiology (ICR) in 1928. ICRP is the internationally recognized body responsible for recommending safety standards for radiation protection. Even if ICRP recommendations do not have any direct force of law, the national legislation in most countries of the world is based on the recommendations of the ICRP.

ICRP models - biokinetic

Describe deposition and movement of radioactive material through the body.

Depend on the intake mode, element, chemical form and physical form, and particle size (inhalation).

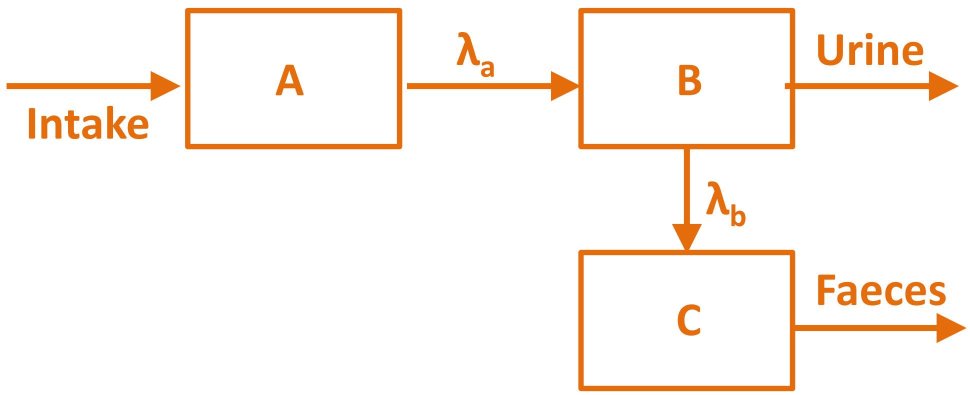
ICRP models - biokinetic

Tissues (including fluids) and organs are COMPARTMENTS.

Transfer routes

Transfer rates

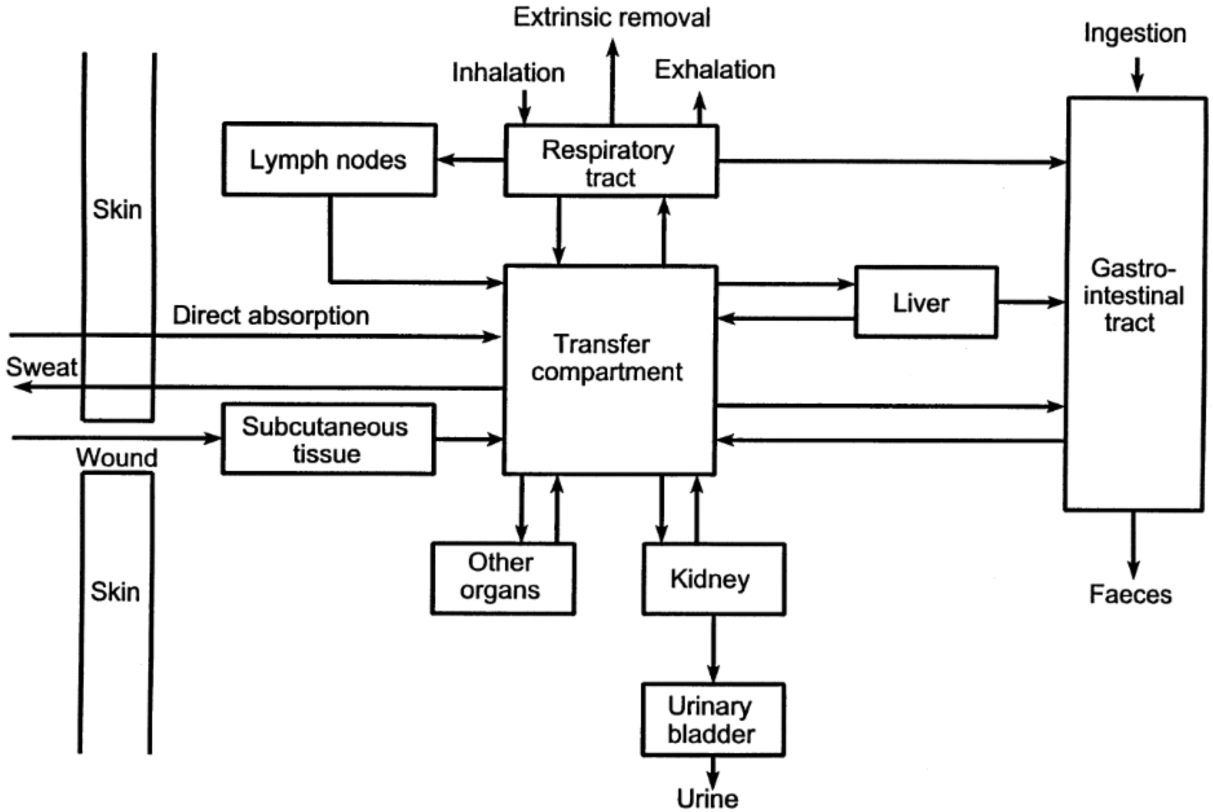
Excretion routes



ICRP models - dosimetric

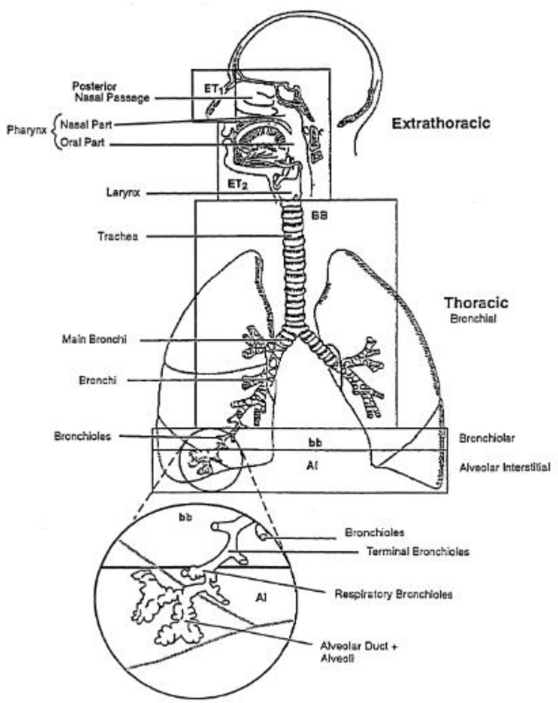
It calculates the micro and macro distribution of the radionuclide within tissues or organs.
It takes into account the decay properties of the radionuclide (particle type and energy).
It uses the radiation weighting factor (w_R) to take into account the biological effectiveness of radiation.
It uses the tissue weighting factor (w_T) to take into account the radiosensitivity of tissues and organs.

ICRP general model (ICRP 78)



ICRP respiratory tract

The human respiratory tract model (ICRP 66, ICRP 78)



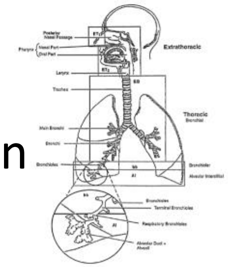
Summing up

The Decision Support System:

- calculates the distribution of radionuclides;
- calculates the dose from external irradiation, using specific dose coefficients;
- calculates the intake and the dose from internal contamination, using specific dose coefficients.

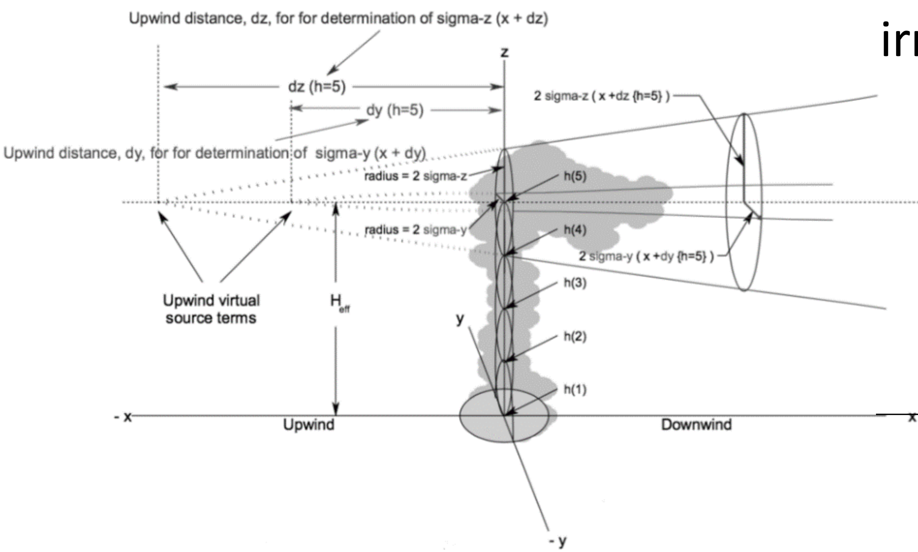
Summing up

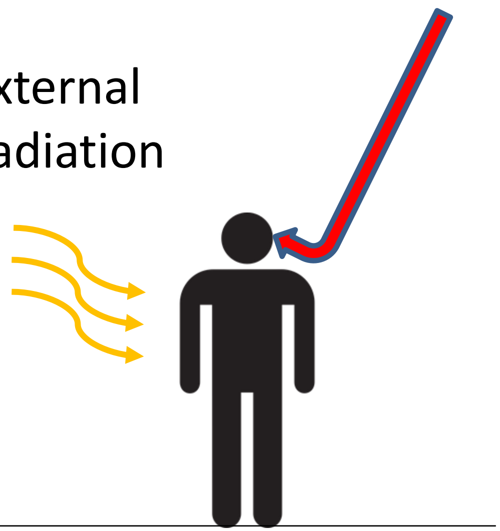
Internal contamination



Dispersion model

External irradiation





APPENDIX
Radiation protection reminder

Radioactive nuclei emit radiation, in the form of particles (alpha, beta, neutrons) or electromagnetic radiation (gamma rays).
X rays are another class of electromagnetic radiation. In most respects, they are identical to gamma radiation.
Radiation interacts with matter, mainly through interactions with atomic electrons in the absorbing medium. The energy transferred may be sufficient to knock an electron out of an atom and thus IONIZE it, or it may leave the atom in an EXCITED, nonionized state.
The absorption of energy by the traversed matter is an important quantity in order to evaluate radiation effects.

The ABSORBED DOSE in a point is defined as the ratio of the mean energy imparted (dε) by ionizing radiation to the matter in a volume element and the mass of the matter (dm) in this volume element.

$$D = d\varepsilon/dm$$

The SI unit of absorbed dose is the gray (Gy). It is defined as an energy deposition of 1 joule per kilogram: 1 Gy = 1 J/kg-
In radiation protection, the mean absorbed dose in an organ or tissue is defined by

$$D_T = \frac{1}{m_T}\int_{m_T} D dm$$

D_T = absorbed dose (Gy); m_T = mass of organ or tissue (kg)

The absorbed dose is insufficient by itself to predict either the severity or the probability of the deleterious effects on health. In biological systems, the same absorbed dose of different types of radiation not necessarily produces the same degree of damage.
The EQUIVALENT DOSE is introduced to take into account the effectiveness of different types of radiation.
The equivalent dose in an organ or tissue T is defined by

$$H_T = w_R D_{T,R}$$

H_T = equivalent dose (Sv);
$D_{T,R}$ = absorbed dose averaged over T due to radiation R (Gy);
w_R = radiation weighting factor for radiation R.

The unit of equivalent dose in SI units is the sievert (Sv).

Recommended radiation weighting factors (ICRP 103)

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons[a] and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy

In order to take into account the not uniform irradiation of the human body and the different susceptibility to radiation of different organs and tissues, the concept of EFFECTIVE DOSE is introduced.
This is obtained by summing the equivalent doses to all tissues and organs of the body multiplied by a weighting factor w_T for each tissue or organ.

The effective dose is defined by

$$E = \sum_T w_T \, H_T \qquad \text{(ICRP 60)}$$

$$E = \sum_T w_T \left[\frac{H_T^M + H_T^F}{2} \right] \qquad \text{(ICRP 103)}$$

H_T = equivalent dose in tissue T (Sv) (M = Male, F = Female, ICRP 103); E = effective dose (Sv).

The unit of effective dose in SI units is the sievert (Sv).
Effective dose is designed as a measure of “radiation detriment” (cancer incidence, cancer mortality, life shortening and hereditary effects). In radiation protection, it is clearly the biological effect of radiation that is of interest and so, whenever possible, effective dose (or equivalent dose) should be used.

Following an intake to the body of radioactive material, there is a period during which radionuclides give rise to equivalent doses in the tissues of the body at varying rates. The time integral of the equivalent-dose rate is called the COMMITTED EQUIVALENT DOSE

$$H_T(\tau) = \frac{1}{m_T}\int_{t_0}^{t_0+\tau} \dot{H}_T(t)dt$$

$\dot{H}_T$ = equivalent dose rate in tissue T. τ = integration time (in years) following the intake. If τ is not specified, it is implied that the value is 50 years for adults and from intake to age 70 years for children.

By extension, the COMMITTED EFFECTIVE DOSE is defined by

$$E(\tau) = \sum_T w_T \, H_T(\tau)$$

For both, the SI unit is sievert (Sv)

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