Part A. Dose magnitudes

1. Definitions
2. Effects of the ionization radiation
3. Natural background
4. Rules for workers & zones

1. Definitions

Ionizing radiation

→ directly ionizing: charged particles (electrons, protons, …)
→ indirectly ionizing: photons, neutrons

of the order of 10 eV required to ionise an atom **(1 eV = 1.6022 10^{-19} J)**

electromagnetic radiation:

$$E = \frac{hc}{\lambda} \Rightarrow \lambda \approx 100 \text{ nm}$$

$$E = 12.4 \text{ eV}$$

(hard ultraviolet)

$h = 6.626 \; 10^{-34}$ J s
$c = 2.998 \; 10^{8}$ m s^{-1}

	Ionization potential (eV)
carbon	11.260
oxygen	13.618
potassium	4.341
iron	7.870
lead	7.416

1. Definitions

Quantities and units used to quantify **stochastic effects:**

Exposure

Absorbed Dose — Energy absorbed per mass unity (Joule/kg; Gray - Gy).

Radiation type weighting factor

Equivalent Dose — (Joule/kg; Sievert - Sv).

Tissue type weighting factor

Effective Dose — (Joule/kg; Sievert - Sv).

1 Sv = 100 rem

1 mSv = 0.1 rem

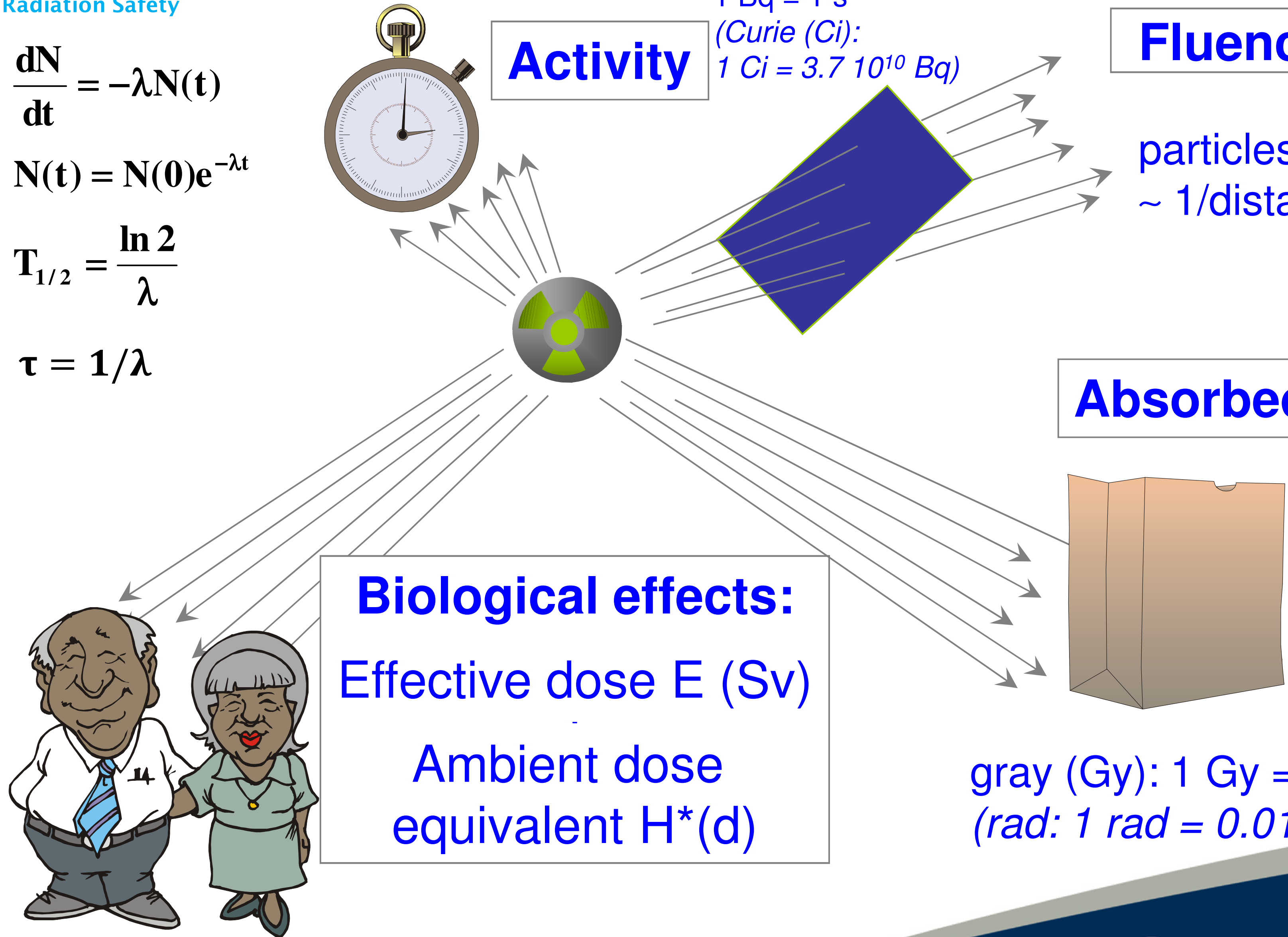
1. Definitions

$$\frac{dN}{dt} = -\lambda N(t)$$

$$N(t) = N(0)e^{-\lambda t}$$

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

$$\tau = 1/\lambda$$



$$D = \frac{d\bar{\varepsilon}}{dm}$$

$$\dot{D} = \frac{dD}{dt}$$

1. Definitions

Ionising Radiation Dose (Equivalent Dose):
is a measure of the radiation dose absorbed by a tissue depending on the different types of ionizing radiation.

1 mSv = 0,001 Sv (Sievert)

Energy absorbed per kilogram: 1 Sv = 1 Joule / 1 kg (1 Joule = 0,25 calories)

Assuming **2000 hours** per year and worker:

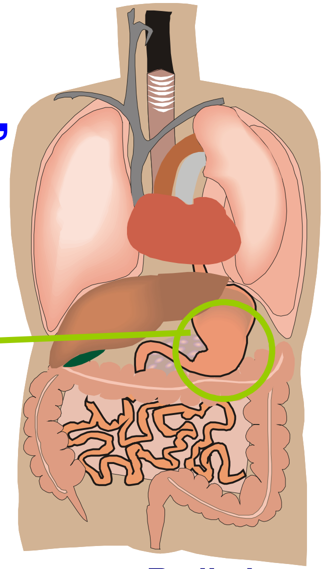
0,001 Sv / 2000 h = 0,0000005 Sv/h = 0,5 µSv/h

juas
Joint Universities Accelerator School
Radiation Safety

1. Definitions

ICRP Publication 60 (1991):

Individual organ, e.g. stomach



Organ dose D_T

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

Tissue or organ equivalent dose $H_{T,R}$

$$H_{T,R} = w_R \cdot D_{T,R}$$

$$H_T = \sum_R w_R \cdot D_{T,R}$$

Type and energy range of radiation	Radiation weighting factor w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons	
< 10 keV	10
10 - 100 keV	5
> 100 keV to 2 MeV	10
>2 - 20 MeV	20
> 20 MeV	10
	5
Protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Unit of equivalent dose: $J.kg^{-1}$
Special name: Sievert (Sv)
Old unit: rem (1 Sv = 100 rem)

Science & Technology Facilities Council
ISIS

1. Definitions

ICRP Publication 60 (1991):

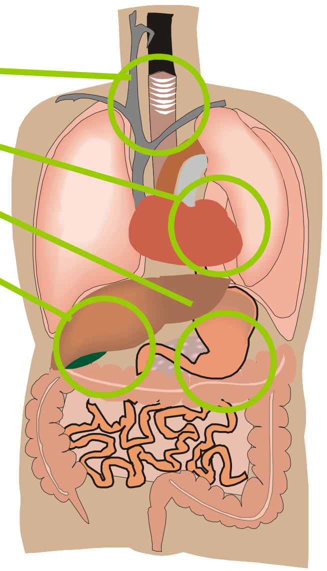
Effective dose E

$$E = \sum_T w_T \cdot H_T$$

Unit of effective dose: Sv

Tissue or organ	Tissue weighting factor w_T
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

Σ different organs



Dose limits on:

a. Effective dose E
b. Tissue or organ equivalent dose H_T

Radiation Safety

ICRP Publication 103 (2007)

Tissue weighting factor w_T

	ICRP 60	ICRP 103
Gonads	0.20	0.08
Bone marrow (red)	0.12	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.12
Liver	0.05	0.04
Oesophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Bone surface	0.01	0.01
Brain	-	0.01
Salivary gland	-	0.01
Remainder	0.05	0.12
Total	1	1

Radiation weighting factor w_R

$$2.5 + 18.2\, e^{-[\ln E_n]^2/6}, \quad E_n < 1\,\mathrm{MeV}$$

$$5.0 + 17.0\, e^{-[\ln 2E_n]^2/6}, \quad 1\,\mathrm{MeV} \le E_n \le 50\,\mathrm{MeV}$$

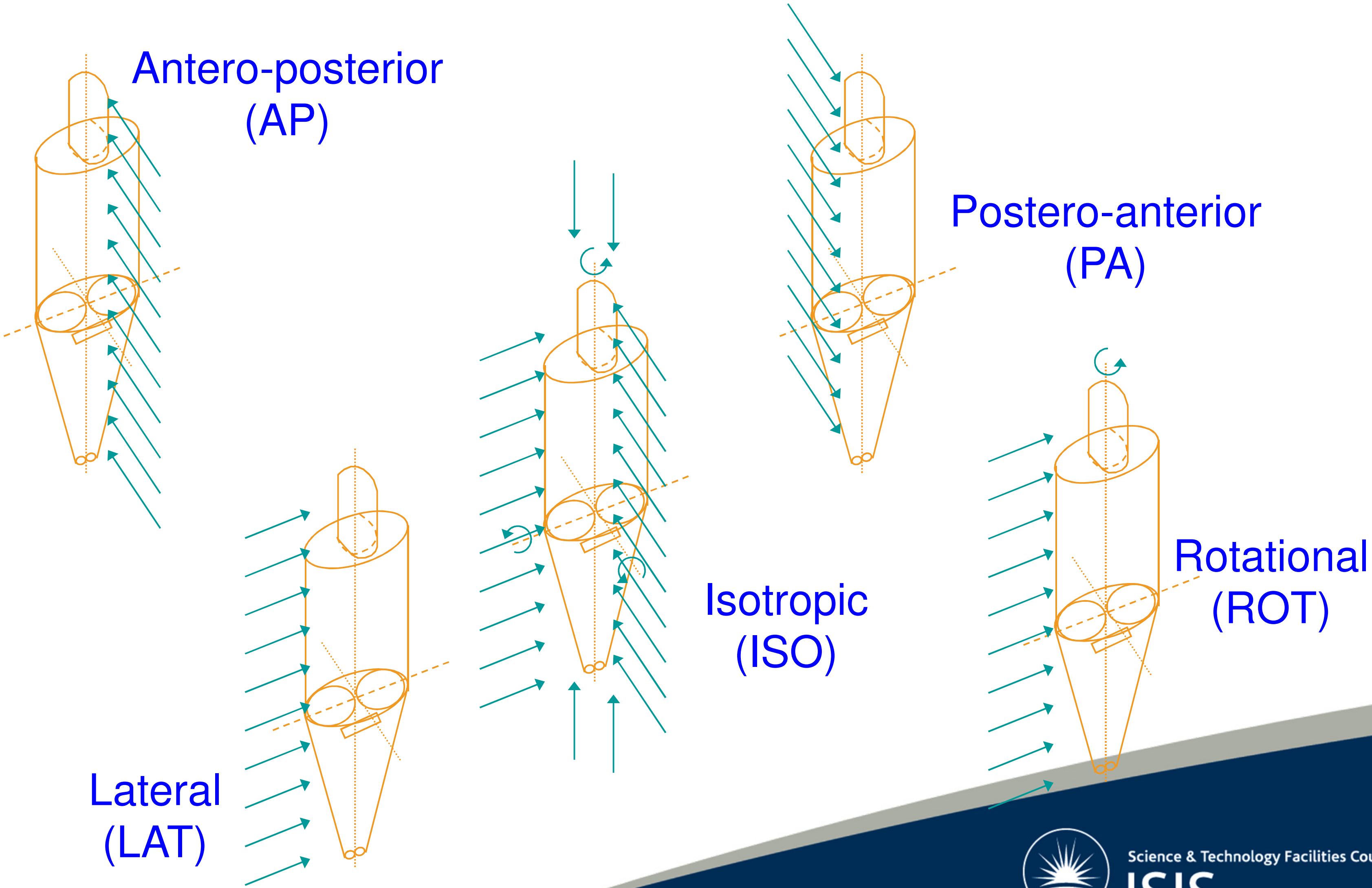
$$2.5 + 3.25\, e^{-[\ln 0.04E_n]^2/6}, \quad E_n > 50\,\mathrm{MeV}$$

neutrons

protons: 2

1. Definitions

ICRP Publication 60 (1991): Irradiation geometries



1. Definitions

ICRU Report 51 (1993):

Protection quantities (ICRP) → operational quantities

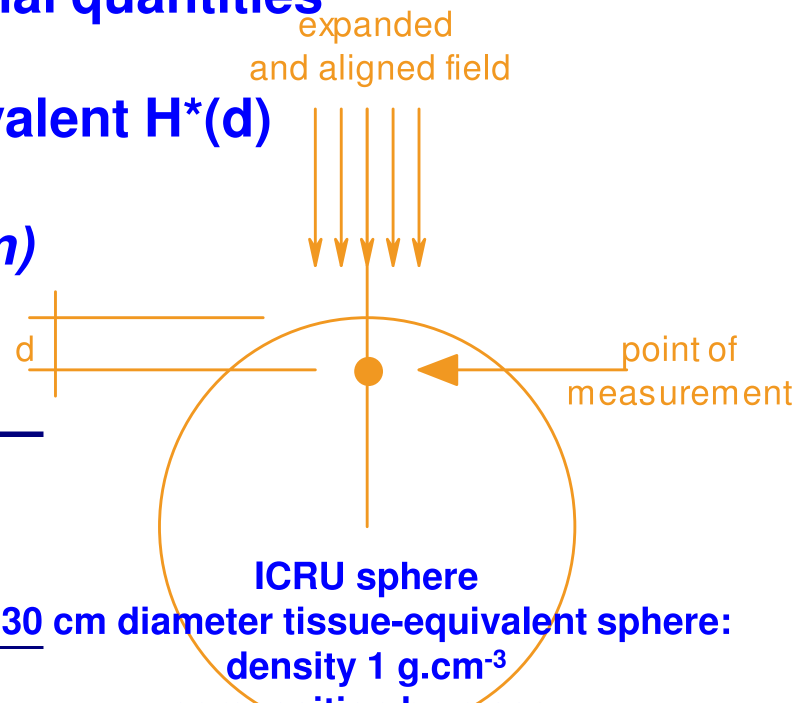
Dose equivalent

$$H = Q \cdot D$$

Unit of dose equivalent: Sv

Ambient dose equivalent H*(d)

→ H*(10) ***(d = 10 mm)***



ICRU sphere
30 cm diameter tissue-equivalent sphere:
density 1 $g.cm^{-3}$
composition by mass:
76.2 % O, 11.1 % C, 10.1 % H and 2.6 % N

Unrestricted linear energy transfer L ($keV \cdot \mu m^{-1}$)	Quality factor Q
$L < 10$	1
$10 \leq L \leq 100$	0.32 L - 2.2
$L > 100$	$300 / L^{1/2}$

2. Effects of the ionization radiation

Radiation

⇩

Electrical Effect (Ionization)

⇩

Physical & Chemical Changes

⇩

Damage to DNA

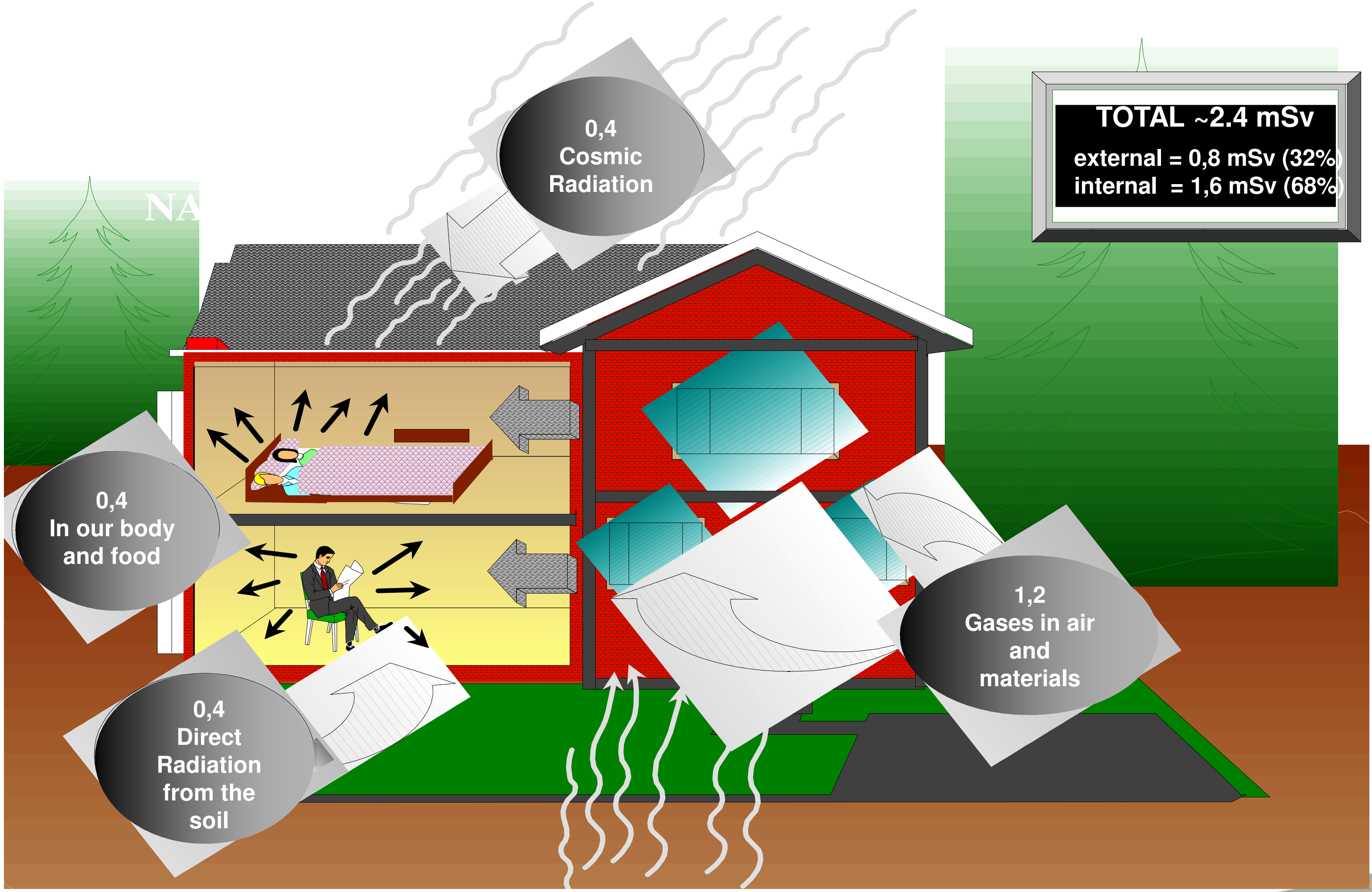
⇩ Cell Death → ⇩ Early Effect

⇩ Cell Transformation → ⇩ Cancer; ⇩ Hereditary Defects

2. Effects of the ionization radiation

Effect	Population	Exposure period	Probability/Sv
Hereditary effects	Whole population	Lifetime	1 % (all generations)
Fatal cancer	Whole population	Lifetime	5 %
	Working population	Age 18-65	4 %
Health detriment	Whole population	Lifetime	7.3 %
	Working population	Age 18-65	5.6 %

3. Natural background

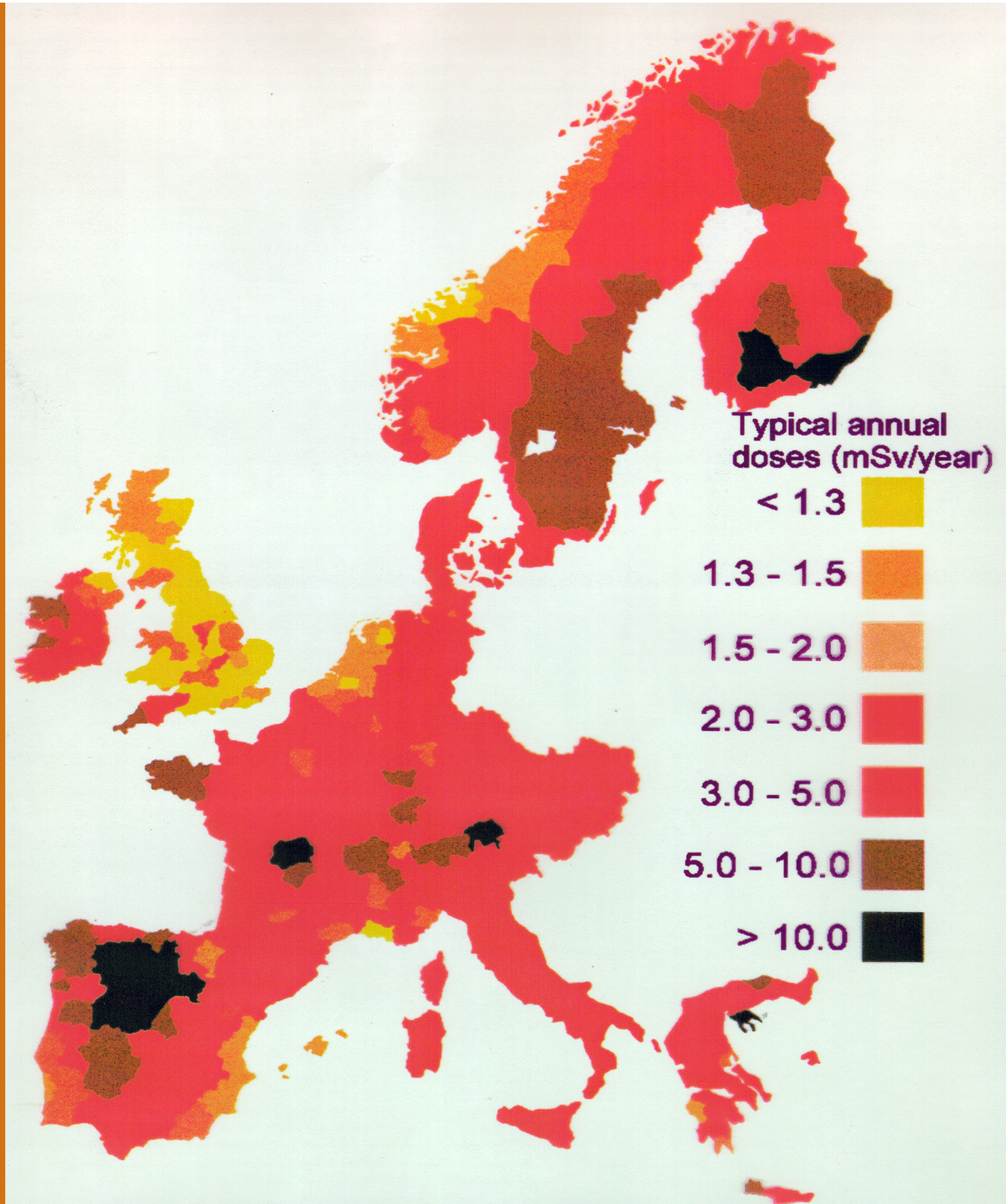


3. Natural background

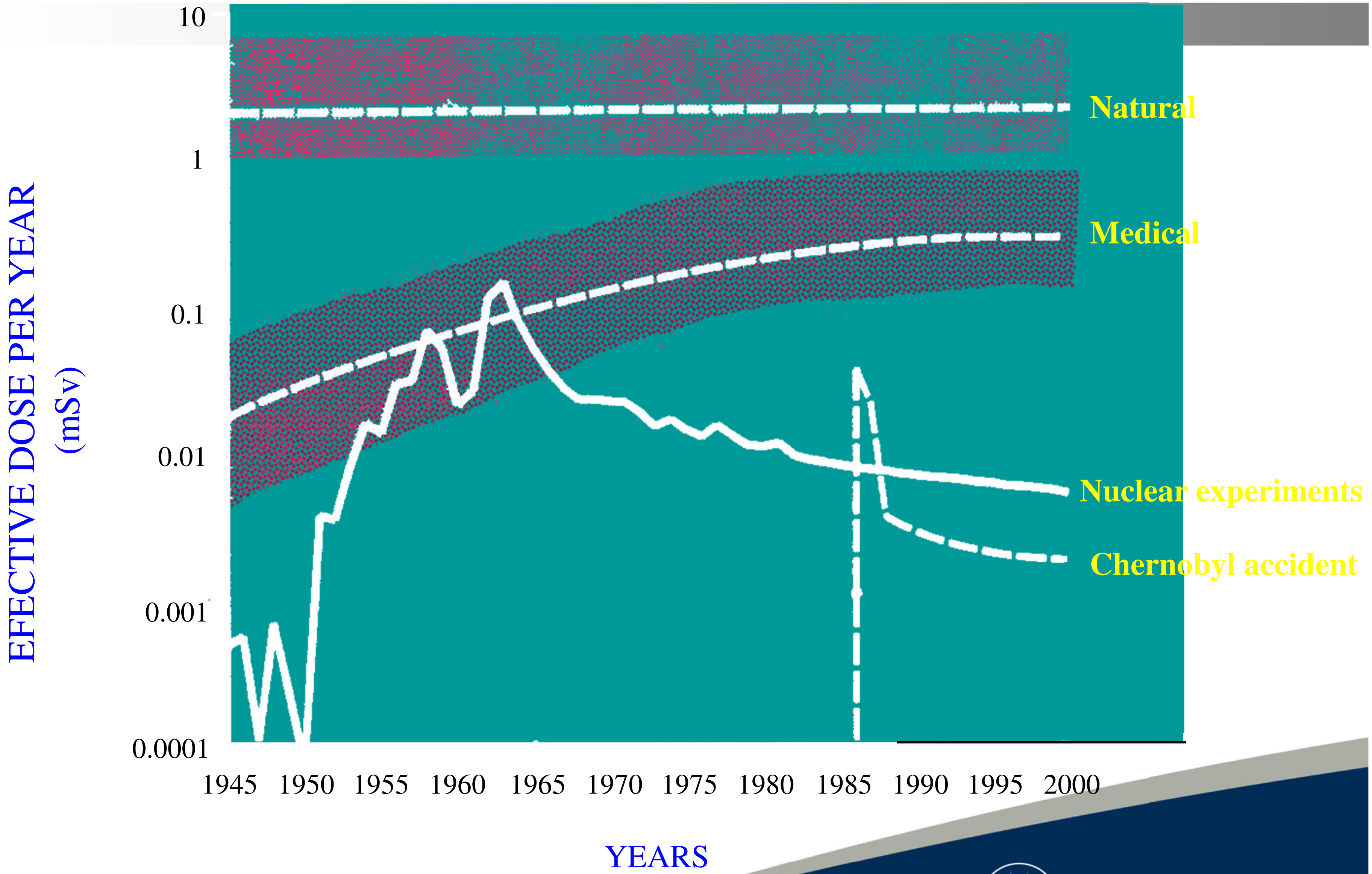
WORLDWIDE AVERAGE DOSES

Source	*Effective dose (mSv per year)*	*Typical range (mSv per year)*
External exposure		
• Cosmic rays	0.4	0.3-1.0
• Terrestrial gamma rays	0.5	0.3-0.6
Internal exposure		
• Inhalation	1.2	0.2-10
• Ingestion	0.3	0.2-0.8
Total	2.4	1–10

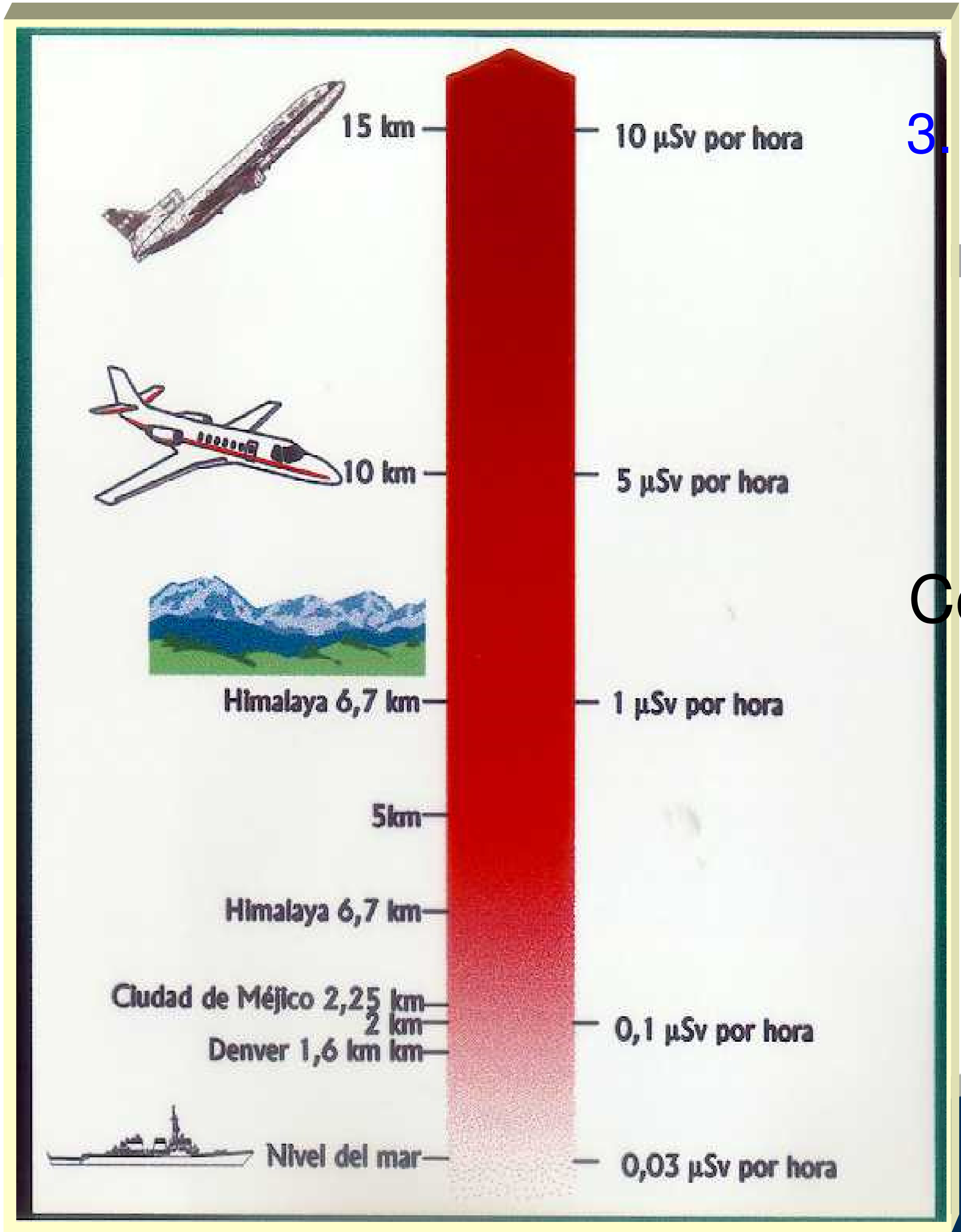
Natural background radiation exposure in Europe



3. Natural background

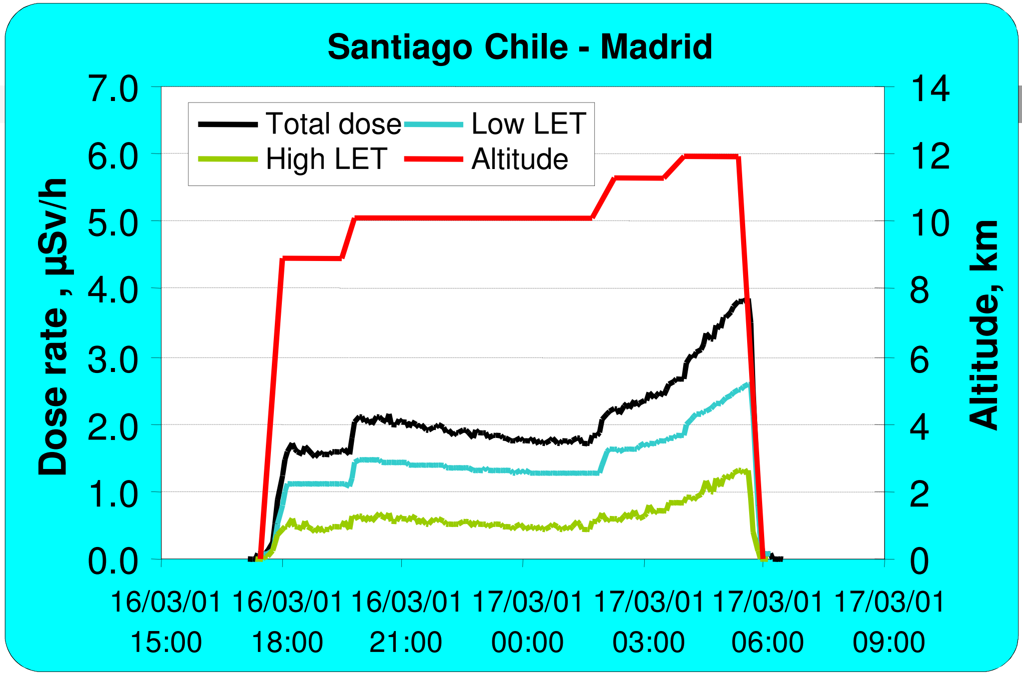


3. Natural background



Cosmic Radiation

3. Natural background



3. Natural background

AVERAGE DOSES TO WORKERS

Radiation source	*Number of workers*	*Average dose* (mSv per year)
Enhanced natural sources		
• **Mining (excluding coal)**	**760,000**	**2.7**
• **Coal mining**	**3,900,000**	**0.7**
• **Air travel (crew)**	**250,000**	**3**
• **Mineral processing**	**300,000**	**1.0**
• **Above ground workplaces (radon)**	**1,250,000**	**4.8**
Total	**6.500,000**	**1.7**

4. Rules for workers & zones

DOSE LIMITS - PERSONAL

- **WORKERS :**

1. For Exposed Workers - A: maximum dose 50 mSv per official year (100 mSv for 5 years)
2. For Exposed Workers - B: maximum dose 6 mSv per official year
3. For None Exposed Workers: 1 mSv per official year
4. For women during pregnancy (*): 1 mSv
5. For general public: 1 mSv per official year

4. Rules for workers & zones

	Dose Limit	
Aplication	Workers	Public
Effective Dose	20 mSv/year averaged for 5 years periods[1]	1 mSv/year[2]
Equivalent Dose (/year):		
Lens (Crystalline)	20 mSv[4]	15 mSv
Skin [3]	500 mSv	50 mSv
Hands and foot	500 mSv	------

1 The effective dose will be below 50 mSv any year.

2 Under exceptional situations a higher effective dose could be accepted, if the average in 5 years Is not above 1mSv/year.

3 These dose limits (equivalent dose) prevent deterministic effects after local exposures.

4 IAEA, 2014. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA Safety Standards Series No. GSR Part 3. International Atomic Energy Agency, Vienna

1 mSv/year is the annual limit for public due to artificial radiations

Exposed Worker

Annual dose (2000 h/year):

< 1 mSv/year

Dose per day:

< 12 μSv

Dose rate @ public areas:

< 0.5 μSv/h

The smoker case

Annual dose (1.5 pack/day):

13 mSv/year

Dose per cigarrette:

~ 1.2 μSv/cigarette

Dose rate (5min/cigarette):

~ 14.4 μSv/h

4. Rules for workers & zones

AREA DOSE LIMITS

- **Area Designation:**

1. **Controlled Area**: dose higher than 6 mSv (per official year)
   - i. Limit Access Zone: dose higher than 100 mSv (for 5 years)
   - ii. Ruled Access Zone: high dose rate (short period)
   - iii. Prohibited Access Zone: high dose (single exposition)

2. **Supervised Area**: dose lower than 6 mSv (per official year)

Always ANNUAL DOSE is ABOVE the background LEVEL

4. Rules for workers & area

DOSE LIMITS - SIGNALS

It is likely than in 1 year:

SUPERVISED AREA from 1 mSv/y to 6 mSv/y

CONTROLLED AREA from 6 mSv/y to 50mSv/y

LIMIT ACCESS AREA Less than a year (months): 50 mSv

RULED ACCESS AREA Less than month (days): 50 mSv

PROHIBITED ACCESS AREA Single exposition (hours): 50 mSv

4. Rules for workers & zones

DOSE LIMITS - SIGNALS

If we assume 2,000 hours/year:

SUPERVISED AREA > 0,5 μSv/h up to 3 μSv/h

CONTROLLED AREA > 3 μSv/h up to 25 μSv/h

LIMIT ACCESS AREA > 25 μSv/h up to 100 μSv/h

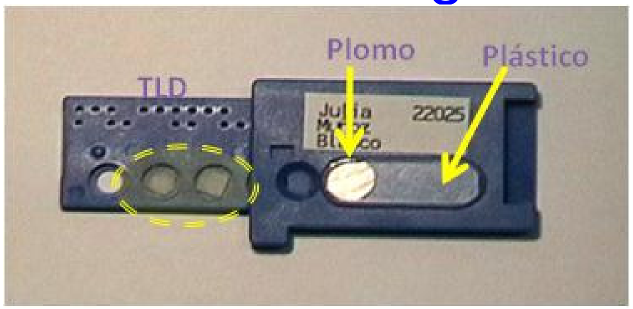
RULED ACCESS AREA > 100 μSv/h up to 25 mSv/h

PROHIBITED ACCESS AREA > 25 mSv/h

4. Rules for workers & zones

Passive personnel dosimeters

- Thermoluminiscense
- Based on detectors TLD-100 (LiF: Mg, Ti):
    - Equivalent dose
    - Range of usage: 10µGy-10Gy.
- The filter system allow to distinguish the energy radiation



Whole body dosimeter

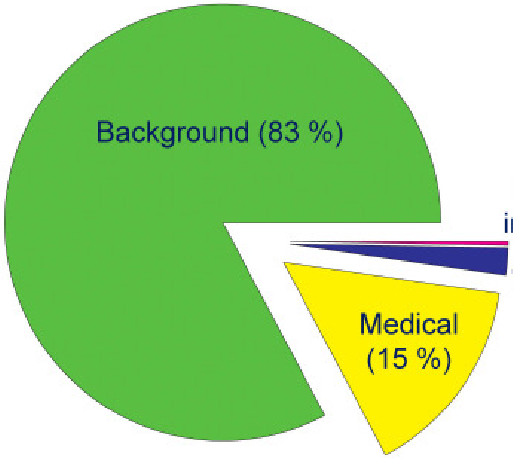
4. Rules for workers & zones

Different passive dosimeters configurations

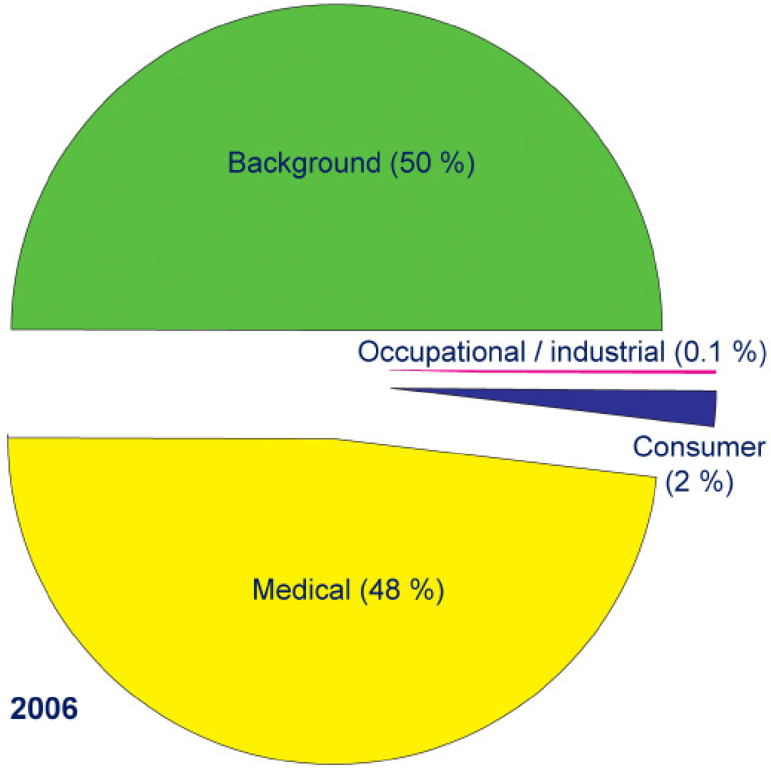
4. Rules for workers & zones

Radiation exposure to US population from all sources. NCRP 160 published 2009

Early 1980s



2006



	Early 1980s	2006
Collective effective dose (person-Sv)	835,000	1,870,000
Effective dose per individual in the U.S. population (mSv)	3.6	6.2
Medical dose per capita (mSv)	**.54**	**3.0**

has increased 560%