Prof François Bochud
Institute of Radiation physics (IRA)
UNIL - CHUV

Master of Science EPF-ETH degree in
Nuclear Engineering
Medical Radiation Physics

Risk and radiation
Learning objectives

• Briefly explain the effects of radiation on human health

• Be able to compare in the day to day life acute and chronic risks

• Understand some psychological aspects of risk perception

• Understand the complexity of communicating about radiation risk
Risk and radiation
1. Effects of ionizing radiations
Dose vs. Effect graph showing tissue reactions appear rapidly above the threshold dose.
How do we define the threshold of tissue reaction? (in terms of *proportion of the population showing the effect*)

1. 1%
2. 5%
3. 10%
4. 50%
5. 90%
Tissue reactions *(aka deterministic effect)*

Most radiosensitive population

Least radiosensitive population
Tissue reactions (aka deterministic effect)
lethal whole body 1-3 months (10-14 Gy)

lethal whole body 1 week (4-8 Gy)

sterility F acute (2.5-6 Gy)

sterility M acute (3.5-6 Gy)

brain growth (1-2 Gy)

very young brain (>0.1 Gy)
Does the risk to develop a radiation-induced cancer have a threshold?

1. Yes, below a given dose, the risk is zero
2. No, whatever the dose, there is a risk
3. Nobody really knows
A lot of information thanks to the survivors of Hiroshima et Nagasaki

- Effects that need time to appear:
  - Cancers
  - CV illness
  - Cataracts
  - Hereditary effect

- Linear non-threshold hypothesis (LNT)
Beaucoup d'informations obtenues grâce aux survivants d'Hiroshima et Nagasaki

Not only Hiroshima et Nagasaki

nuclear workers
miners
radon residents
radiation therapy patients
radiation diagnostic patients
Chernobyl
natural irradiation

effects that need time to appear (cancers, CV illness) (cataracts, hereditary effect)

Linear non-threshold hypothesis (LNT)
probability to develop a cancer after a whole body absorbed dose of 100 mGy
Risk and radiation

2. Quantifying risk
(at least its probability)
What is the probability to die today? 
(all causes combined, in a developed country)

1. $20 \times 10^{-8}$
2. $20 \times 10^{-7}$
3. $20 \times 10^{-6}$
4. $20 \times 10^{-5}$
5. $20 \times 10^{-4}$
6. $20 \times 10^{-3}$
7. $20 \times 10^{-2}$
## Probability to die per day

*(all causes ; whole population)*

<table>
<thead>
<tr>
<th>Context</th>
<th>Time period</th>
<th>N deaths</th>
<th>N population</th>
<th>$10^{-6}$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>England and Wales</td>
<td>2012</td>
<td>499,331</td>
<td>56,567,000</td>
<td>24 per day</td>
<td>ONS Deaths Table 5.</td>
</tr>
<tr>
<td>Canada</td>
<td>2011</td>
<td>242,074</td>
<td>33,476,688</td>
<td>20 per day</td>
<td>Statistics Canada</td>
</tr>
<tr>
<td>US</td>
<td>2010</td>
<td>2,468,435</td>
<td>308,500,000</td>
<td>22 per day</td>
<td>CDC Deaths Table 18.</td>
</tr>
</tbody>
</table>

About $20 \times 10^{-6}$ per day

[https://en.wikipedia.org/wiki/Micromort](https://en.wikipedia.org/wiki/Micromort)
In Switzerland

31 257 + 33 704 = 64 961 death in 2013

\[
\frac{64961}{8 \cdot 10^6 \cdot 365} = 22.2 \cdot 10^{-6} \text{ deaths per day per inhabitant}
\]
Today statistics in Switzerland

Enregistrement continu des décès en 2016


http://www.bfs.admin.ch/bfs/portal/fr/index/themen/14/02/04/key/01.html
What is the probability to die today?
(of a non-natural cause, in a developed country)

1. $1 \times 10^{-8}$
2. $1 \times 10^{-7}$
3. $1 \times 10^{-6}$
4. $1 \times 10^{-5}$
The probability to die from a non-natural cause in the general population is about $1 \times 10^{-6}$ per day.

$10^{-6}$ is 1 MicroMort
In Switzerland

2597
\[ \frac{8 \cdot 10^6 \cdot 365}{2597} \]
= \(0.89 \cdot 10^{-6}\)
deads per day
derm per inhabitant

2597 people

http://www.bfs.admin.ch/bfs/portal/fr/index/themen/14/02/04/key/01.html#parsys_84305
In Switzerland

http://www.bfs.admin.ch/bfs/portal/fr/index/themen/14/02/04/key/01.html#parsys_84305
## Examples of MicroMorts
*(leisure and sport)*

<table>
<thead>
<tr>
<th>Death from</th>
<th>Context</th>
<th>Time period</th>
<th>N deaths</th>
<th>N exposure</th>
<th>MicroMorts</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scuba diving</td>
<td>UK <em>(BSAC members)</em></td>
<td>1998-2009</td>
<td>75</td>
<td>14,000,000 dives</td>
<td>5 per dive</td>
<td>BSAC</td>
</tr>
<tr>
<td></td>
<td>Scuba diving</td>
<td>1998-2009</td>
<td>122</td>
<td>12,000,000 dives</td>
<td>10 per dive</td>
<td>BSAC</td>
</tr>
<tr>
<td></td>
<td>Scuba diving</td>
<td>2000-2006</td>
<td>187</td>
<td>1,131,367 members</td>
<td>5 per dive</td>
<td>DAN p75</td>
</tr>
<tr>
<td>Skiing</td>
<td>US</td>
<td>2008/9</td>
<td>39</td>
<td>57,000,000 days skiing</td>
<td>0.7 per day</td>
<td>Ski-injury.com</td>
</tr>
<tr>
<td>Skydiving</td>
<td>US</td>
<td>2008-2013</td>
<td>135</td>
<td>15,300,000 jumps</td>
<td>9 per jump</td>
<td>USPA</td>
</tr>
<tr>
<td>Skydiving</td>
<td>UK</td>
<td>1994-2013</td>
<td>41</td>
<td>4,864,268 jumps</td>
<td>8 per jump</td>
<td>BPA</td>
</tr>
<tr>
<td>Running marathon</td>
<td>US</td>
<td>1975-2004</td>
<td>26</td>
<td>3,300,000 runs</td>
<td>7 per run</td>
<td>Kipps C 2011</td>
</tr>
<tr>
<td>Mountaineering</td>
<td>Ascent to Mt. Everest</td>
<td>1922-2012</td>
<td>223</td>
<td>5,656 ascents</td>
<td>39,427 per ascent</td>
<td>NASA 2013</td>
</tr>
</tbody>
</table>

*https://en.wikipedia.org/wiki/Micromort*
What is an unacceptable risk?

(for workers; i.e. occupational risk)

1. 1 MicroMort /year
2. 10 MicroMort /year
3. 100 MicroMort /year
4. 1'000 MicroMort /year
5. 10'000 MicroMort /year

according to the British Health and Safety Executive (HSE)

about 3 MicroMort/day
Limit for **occupational** exposures

*(for stochastic risk)*

- Annual death probability
  - Regular irradiation, during the whole professional life, at a given dose

- **Limit: 20 mSv/year**

1000 MicroMort per year

*(more is unacceptable)*
What is an unacceptable risk? (for the public)

1. 1 MicroMort /year
2. 10 MicroMort /year
3. 100 MicroMort /year
4. 1'000 MicroMort /year
5. 10'000 MicroMort /year

according to the British Health and Safety Executive (HSE)

about 0.3 MicroMort/day
Limit to the **public** (for *stochastic risk*)

- Annual death probability
  - Regular irradiation, lifelong, at a given dose

- **Limit:** 1 mSv/year

In fact, the consensus justification of the risk associated to the limit for the public has changed with time:

Now it is defined as the typical dose coming from the **natural background**

100 MicroMort per year *(more is unacceptable)*
**MicroMort** is useful for an **acute event** leading to a directly attributable death

**Murder** with a chainsaw is an **acute** risk, **obesity** is a **chronic** one that takes time to do its worst *(so do low doses of radiations)*

For **chronic risks**, we can use the concept of **MicroLife**

M. Blastland and D. Spiegelhalter, The Norm Chronicles, Stories and Numbers About Danger, Profile Books, 2013
How many half-hours of life can you expect when you enter adulthood?

1. 1 000
2. 10 000
3. 100 000
4. 1 000 000
5. 10 000 000
Like MicroMort, MicroLife brings life down to a micro level that's easy to think about and compare:
The simple passing of time uses up **48 MicroLives a day**

Lung cancers and heart disease often follows a lifetime's **smoking** and subsequently **reduces life expectancy**

*(not for everyone, but overall)*
Chronic risks don't kill us straight away, but they tend to **kill us sooner** than if we avoid them.

The exposure to a chronic risk of **1 MicroLife** shortens life on average **by one** of the million **half-hours** that we have left when we enter adulthood.
MicroLives can decrease or increase life span
MicroLives can decrease or increase life span.
MicroLives can decrease or increase life span
Examples of MicroLives

- Doing a 20 min exercise gives you 2 additional MicroLives (at the end of the day, you actually used 46 MicroLives)
- Smoking 15-24 cigarettes uses 10 additional MicroLives (at the end of the day, you actually used 58 MicroLives)

Taking long-time risk (or positive behavior) can be understood as changing the pace of time.
Exercise
compute the average time loss
for an effective dose of 20 mSv

Simplistic hypotheses

Risk to die: 5% Sv⁻¹
Latency: L=20 years (assume that those who will die, will do it exactly at this time)
Life expectancy: 80 years
Possible expositions between e=20 and e=60 years old
Exercise (solution)
compute the average of time loss
for an effective dose of 20 mSv

Simplistic hypotheses
Risk to die: $5\% \text{ Sv}^{-1}$
Latency: $L=20$ years (assume that those who will die, will do it exactly at this time)
Life expectancy: 80 years
Possible expositions between $e=20$ and $e=60$ years old

risk to die: $r = 0.02 \times 0.05 = 1/1000$

life loss if exposed at 20 y.o.: $r \times (80-40) = 40/1000 = 0.04$ years = 14.6 days
# Examples of MicroLives

<table>
<thead>
<tr>
<th>Exposure</th>
<th>E [mSv]</th>
<th>Average loss in life expectancy</th>
<th>MicroLives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual occupational limit</td>
<td>20</td>
<td>7 days</td>
<td>400</td>
</tr>
<tr>
<td>Whole body CT scan</td>
<td>10</td>
<td>3 days</td>
<td>150</td>
</tr>
<tr>
<td>Fukushima prefecture</td>
<td>1 – 10</td>
<td>10h – 3d</td>
<td>20 - 150</td>
</tr>
<tr>
<td>Fukushima Town Hall in the two weeks following accident</td>
<td>0.1</td>
<td>1 h</td>
<td>2</td>
</tr>
<tr>
<td>Flight from London to New-York</td>
<td>0.07</td>
<td>37 min</td>
<td>1</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>0.02</td>
<td>11 min</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Nota bene*

We assume the linear non-threshold (LNT) hypothesis

These are **average values**

The **tolerability** of risk depends on **many other aspects**
For more information about MicroMort and MicroLives, visit the link below

Risk and radiation
3. Risk perception
Risk is highly subject to bias of perspective
The probability of dying of "normal gun violence" is higher than of dying of a terror attack *(in the USA; years 2014-2013)*

1. wrong, **1000** times smaller
2. wrong, **100** times smaller
3. wrong, **10** times smaller
4. wrong, it is the **same**
5. true, **10** times higher
6. true, **100** times higher
7. true, **1000** times higher
NUMBER OF AMERICANS DEATHS CAUSED BY TERRORISM VS. GUN VIOLENCE

For every American killed by terrorism in the U.S. and around the world, more than 1,000 were killed by firearms inside the U.S. during the most recent decade for which comparative data is available.

![Graph showing American deaths by firearms on U.S. soil and total American deaths by terrorism from 2004 to 2013.]

Source: Centers for Disease Control and Prevention, U.S. State Department
During the Fukushima accident, the discussion was more about (possible) impact than probabilities.
For a given cost, which action do you choose?

1. Transform the Gotthard tunnel in order to avoid a large accident
2. Mark all Swiss roads with fluorescent painting in order to reduce many small accidents
Acceptation of "objective risk"

We give much **more weight to large impacts events**; even if they are **not frequent**

31 deaths in the London underground fire on 18.11.1987

- The government invested **300 M£** to reduce the risk of **another fire in the underground**
- The same amount could have paid **smoke detectors** in all British homes
  - Each year, **500 people are killed** by fires in Britain
  - A large part could be saved by installing smoke detectors
## Cost of a Year of Life Saved by Various Interventions

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Cost (in $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flu shots</td>
<td>$500</td>
</tr>
<tr>
<td>Water chlorination</td>
<td>$4,000</td>
</tr>
<tr>
<td>Pneumonia vaccinations</td>
<td>$12,000</td>
</tr>
<tr>
<td>Breast cancer screening</td>
<td>$17,000</td>
</tr>
<tr>
<td>All medical interventions</td>
<td>$19,000</td>
</tr>
<tr>
<td>Construction safety rules</td>
<td>$38,000</td>
</tr>
<tr>
<td>All transportation interventions</td>
<td>$56,000</td>
</tr>
<tr>
<td>Highway improvement</td>
<td>$60,000</td>
</tr>
<tr>
<td>Home radon control</td>
<td>$141,000</td>
</tr>
<tr>
<td>Asbestos controls</td>
<td>$1.9 million</td>
</tr>
<tr>
<td>All toxin controls</td>
<td>$2.8 million</td>
</tr>
<tr>
<td>Arsenic emission controls</td>
<td>$6.0 million</td>
</tr>
<tr>
<td>Radiation controls</td>
<td>$10.0 million</td>
</tr>
</tbody>
</table>