HOW USEFULL IS THE DOSE ASSESSMENT FOR THE MANAGEMENT OF AN IRRADIATION ACCIDENT

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Radiological accidents: *different situations of overexposure*

- **External**: 84%
- **Internal**: 10%
- **Mixed**: 3%
- **Not defined**: 3%

- **Whole body**: 12%
- **Very heterogeneous**: 10%
- **Localised + whole body**: 12%
- **Localised**:

More than 600 incidents/accidents are known since 1945 (~200 deaths)
Multidisciplinary expertise and technical support to hospitals

- National authorities
  - Request

- IAEA

- IRSN

- Researchers
  - Suitable dosimetry techniques
  - New therapeutic approaches

- Experienced and reactive teams

- Physical dosimetry
- Biological dosimetry
- Radiopathology

- Hospital
  - i.e. Percy Military Hospital (HIA)

- Physicians
  - Medical management of the victims
Why dosimetry?

- **Medical management of the victims**
  
  *Dose is a marker of damages to tissues and organs which helps the physicians:*
  
  - to evaluate the radio-induced damages
  - to define the therapeutic strategy

- **Aim of the dosimetry:** *assessment of the dose and the dose distribution in the body*
Each accident is particular: *type of source, type of radiation, energy, exposure time, scenario*...

...by using complementary means

- Clinical observations: symptomatology
- Biological dosimetry: study of DNA misrepairs
- Physical dosimetry:
  - Dose reconstruction (*experimental & numerical techniques*)
  - Dosimetry on materials collected on the victim
Experimental tools

Dummies equipped with dosemeters

« Small »
dosemeters
Numerical tools (1)

Numerical anthropomorphic model + Monte Carlo calculations

- Monte Carlo code
- Phantom in the environment
- Simulation of the transport of particles through matter - determination of the energy deposition
- Medical images (CT, MRI)
- Segmentation
Numerical tools (2)

Voxel phantom: dose distribution (SESAME software)
Retrospective dosimetry using ESR

ESR (*electron spin resonance*) dosimetry: measurement of free radicals created in some irradiated materials

- « X band » spectrometer (9 GHz) : sample 100 mg
- « Q band » spectrometer (34 GHz) : sample 2-3 mg
Biological dosimetry

Numbering of chromosome aberrations in the blood
THREE EXAMPLES REPRESENTATIVE OF IRRADIATION ACCIDENT

**Chile (December 2005)** – localized irradiation

**Belgium (March 2006)** – whole body irradiation

**Peru (January 2012)** – localized irradiation to the hands + whole body
Chile accident: circumstances

Place and date: building site of a manufactory, December 15, 2005

Context: a worker found a $^{192}$Ir source from a gammagraphy device. He handled it with his bare hands and put it in the back left-hand pocket of his pants before it was detected by someone with an electronic dosemeter.

Source characteristics:
Iridium-192, $3.3 \times 10^{12}$ Bq (90 Ci)

Irradiation characteristics:
- exposure duration: 10 min in the back left-hand pocket of his pants;
- suspicion of localised exposures: buttock, hands, head and torso

The IAEA appointed IRSN to investigate on-site;
The victim was transferred to France on 29 December 2005 for treatment at the Percy Military Hospital
Medical problematic / support of dosimetry

Localized irradiation → medical management = surgery?

- **Need for an adequate surgery** i.e. remove the correct quantity of tissue to avoid the propagation of necrosis + graft of mesenchymal stem cells (MSC)

- Healthy tissue in appearance the first days or weeks can finally lead to a necrosis if the dose > 25 Gy

**Objective of dosimetry:** provide the position in depth and in surface of the 25 Gy isodose
Chile accident: numerical dose reconstruction

CT images

Voxel phantom

Calculations of the dose distribution in different points within the body
Chile accident: dose reconstruction (10 min exposure)

1900 Gy at the surface of the skin
20 Gy at 5 cm in depth
Chile accident: surgery (Percy Hospital)

Surgery guided by the dosimetry

Dose distribution

1900 Gy
25 Gy
20 Gy
10 Gy
5 Gy
1 Gy

5 cm

10 months after surgery + skin and MSC grafts
Chile accident: ESR measurements on teeth

Assessment of the dose to the head

Tooth 2-4: 8.5 Gy
Tooth 4-5: 5.6 Gy

Addition dose curve

High dose, but no necrosis expected at the head level
Accident in Belgium: *circumstances*

**Place and date:** industrial irradiation facility, Fleurus, March 11th, 2006

**Context:** a worker went inside a cell of irradiation whereas the source was not in the storage position

**Source characteristics:**
- cobalt-60, 30000 TBq (800 000 Ci)

**Irradiation characteristics:**
- exposure duration: 20 s
- whole body exposure

The victim was transferred to the Haematological Department of the Percy Military Hospital on March 31st, 2006

Patient was in medullar aplasia - bone marrow areas were irradiated

IRSN
Accident in Belgium: *circumstances*
Accident in Belgium: *circumstances*
Medical problematic / support of dosimetry

Whole body irradiation  ➔ spontaneous secondary resumption of bone marrow activity?

**Important to know** if some areas of bone marrow were underexposed (below 6 Gy if homogeneous) to lead to a spontaneous secondary resumption of bone marrow activity in these areas.

**Support of dosimetry** to estimate the dose to the different bone marrow areas.
Accident in Belgium: on site measurements

Positioning of dosimeters in a section of the phantom

Tissue-equivalent anthropomorphic phantom fitted with dosimeters and positioned in the irradiation room
Accident in Belgium: *calculations in laboratory*

**Front view**
- Skull: 1.5 Gy
- Sternum: 2.3 Gy
- Iliac crests: 3.4 Gy

**Back**
- Skull: 3.3 Gy
- Upper spine: 3.3 Gy
- Spine: 4.8 Gy
- Iliac crests: 6.4 Gy

Mean dose to the whole body = 4.6 Gy
*(coherent with biological dosimetry)*

Dose gradient corresponding to a factor of 2 in AP and between the pelvis and the skull

The fact that some areas of bone marrow are clearly under-exposed compared with others, given the dose levels, suggests *spontaneous secondary resumption* of bone marrow activity in these areas.
Peru accident: *circumstances*

**Place and date:** hydroelectric company in Chilca, January 12, 2012

**Context:** 3 workers were conducting in-situ gammagraphy activities in several pipes. The $^{192}$Ir source was not in the lead container but somewhere in the flexible cable.

**Source characteristics:**
Iridium-192, 3.6 TBq (98 Ci)

**Irradiation characteristics:**
- exposure duration: ~ 2.5 hours
- **localised exposure to the hands** + **whole body exposure**
Peru accident: localized irradiation signs

Worker 1
Medical problematic / support of dosimetry

Taking into account the testimony of the operators and regarding the clinical observations and the initial dosimetric data, the dose is very high and heterogeneous, both to the whole body and to the hands. These results can be explained only if we consider a global exposure in the vicinity of the source for several hours and a very localised exposure (finger(s) in contact to the collimator for a very short time).

- Localized irradiation + Whole body irradiation
- MSC graft? Amputation?
- Hematopoietic problem?

Support of dosimetry to estimate the dose at the finger(s) level and the dose heterogeneity in the body
Peru accident: dose reconstruction

Global exposure configuration
The calculations show that 40 cm is roughly the mean distance between the source and the victim consistent with the 2.5 hours scenario and the dosimetric data results at whole body level and hands obtained by measurements.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean trunk dose (Gy)</th>
<th>Tooth (Gy)</th>
<th>Chest (location of the passive dosemeter) (Gy)</th>
<th>Hands (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement</td>
<td>2.5 – 3.5*</td>
<td>4**</td>
<td>6-7***</td>
<td>~35****</td>
</tr>
<tr>
<td>Calculations</td>
<td>2.8</td>
<td>3.2</td>
<td>6</td>
<td>20 (hands)</td>
</tr>
</tbody>
</table>

* biological dosimetry
** EPR dosimetry - average between both teeth
*** individual passive dosemeter (from dosimetry lab in Peru)
**** EPR dosimetry - average among nails (total dose: global + localised irradiations)

Localised exposure configuration
The additional dose at the entrance of the left index (in contact to the source holder) is 70 Gy for 20 s, and the dose at the nail level is 10 Gy.
Peru accident: dose assessment at hands using ESR measurements on fingernails and bones

Fingernails used for the first time!
Complementary techniques are needed depending on the accident configuration: biological dosimetry, calculations, ESR...

- Localised irradiation on tissue: surgery area? (calculation with voxel phantoms)
- Localised irradiation at hand: necrosis? MSC graft? (ESR on fingernails)
- Whole body irradiation: hematological symptoms? (biological dosimetry, calculation)

Conclusion

Dosimetry: a key point for therapeutic strategy