Irradiation facilities for biological samples – towards the ideal installation

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Introduction

- The Strategic Research Agenda (SRA) of MELODI acknwoleadge the need for suitable infrastructures:
  - cohorts,
  - **irradiation facilities,**
  - data for and biobanks and
  - platforms for high throughput analysis.
- Available irradiation facilities in Europe were identified within the WP4 of the DoReMI project (45 irradiation facilities in 5 countries).
- Irradiation facilities for biological samples are presents at:
  - research institues
  - calibration laboratories in the field of ionisation radiation – metrology laboratories and EURAMET members ?
  - Hospitals – radiotherapy, radiology and nuclear medicine departments.

Example of irradiation laboratory

Laboratory for Nuclear Calibrations (LNK) of SCK-CEN (since ~1980's):

- initial main activity was calibration of dosemeters
- number of irradiations of biological samples increased over the years -> significant activity
- many radioactive sources available, with good characterisation and traceability to international standards (γ-rays, X-rays, some weak β sources, neutrons)
- limited space available- long term irradiations are difficult to plan
- flexible schedule and easy to plan
- since 2013 LNK is member BELMET and EURAMET (designated metrology laboratory for ionising radiation in Belgium)

Example of irradiation laboratory

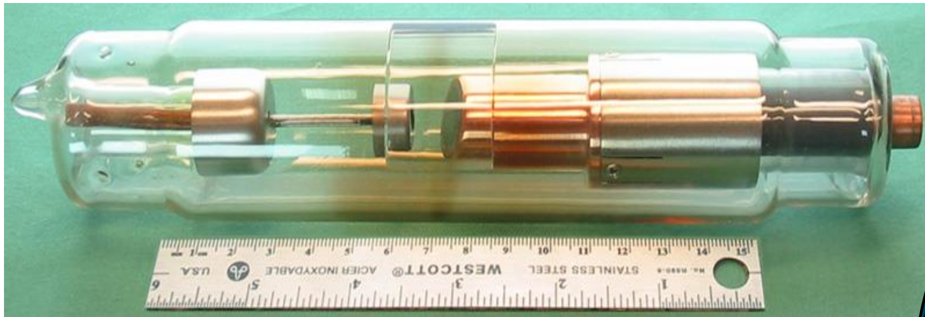
LNK Mol

- dedicated facility for dosimetry calibrations and irradiations
- 2 irradiation rooms + 1 control room
- sources of ^{137}Cs, ^{60}Co, X-rays (10-320 keV), neutrons (^{252}Cf ~2 MeV neutrons and Am-Be ~ 4 MeV neutrons)
- thick walls of barite concrete for radioprotection – limit the dose rate
- H*(10) rates up to few Sv/h (only mSv/h for neutrons).

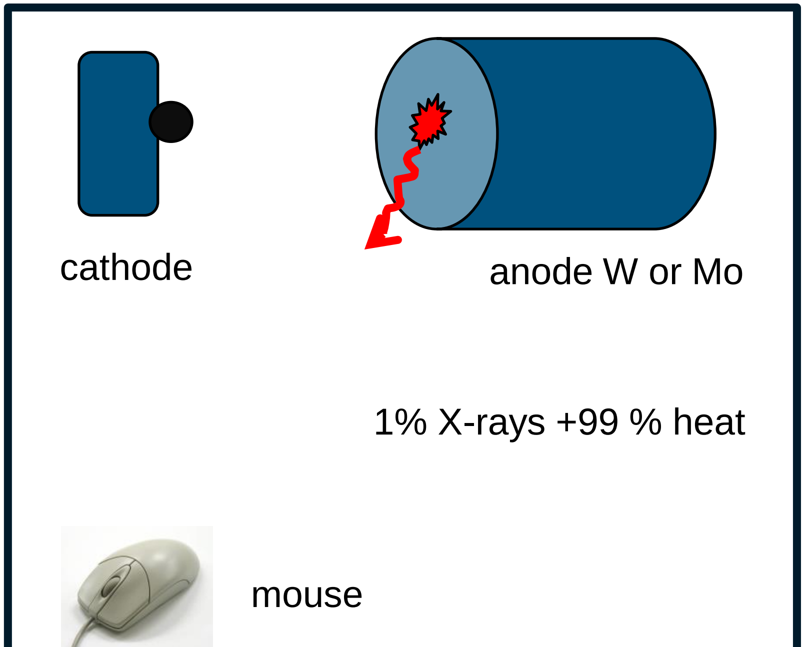
Source types – particles and energies

- Source types and particles emitted (strong energy dependance of the interaction with matter):
  - γ-rays
    - » ^{137}Cs and ^{60}Co – the most frequent)
    - » MV photons – radiotherapy departments of the hospitals – accelerators
  - X-rays
    - » X-ray generators – typical energies available 10- 400 keV.
    - » medical applications used the lower energies
    - » continuous energy spectrum
    - » energies are defined according to generally accepted standards and protocols (ISO, IAEA) ?
    - » main parameters of the X-ray beams: average energy (keV) , resolution (keV or %)
  - neutrons
    - » neutron sources: ^{252}Cf (2 MeV), ^{252}Cf with moderator (0.025 eV), Am-Be (4 MeV), Am-B, Am-F or Am-Li
    - » continuous energy spectrum – high energy + thermal neutron nergies
  - electrons (β)
    - » accelerators (radiotherapy)
  - alpha (α) particles, p, ^{12}C – more exotic
    - » difficult to use → strong attenuation

Energies of the particles – X-ray spectra



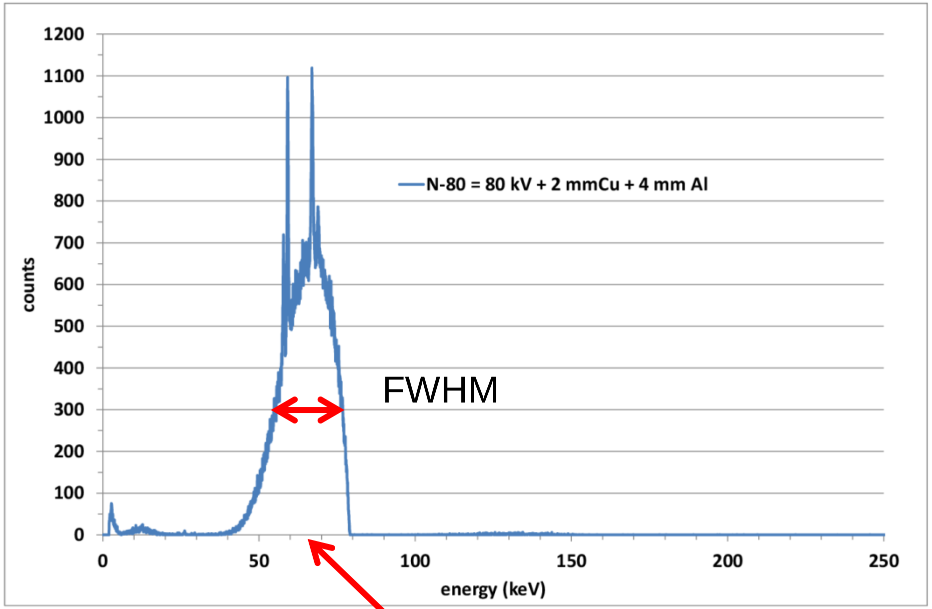
Typical X-ray tube (Source photo : Wikipedia)



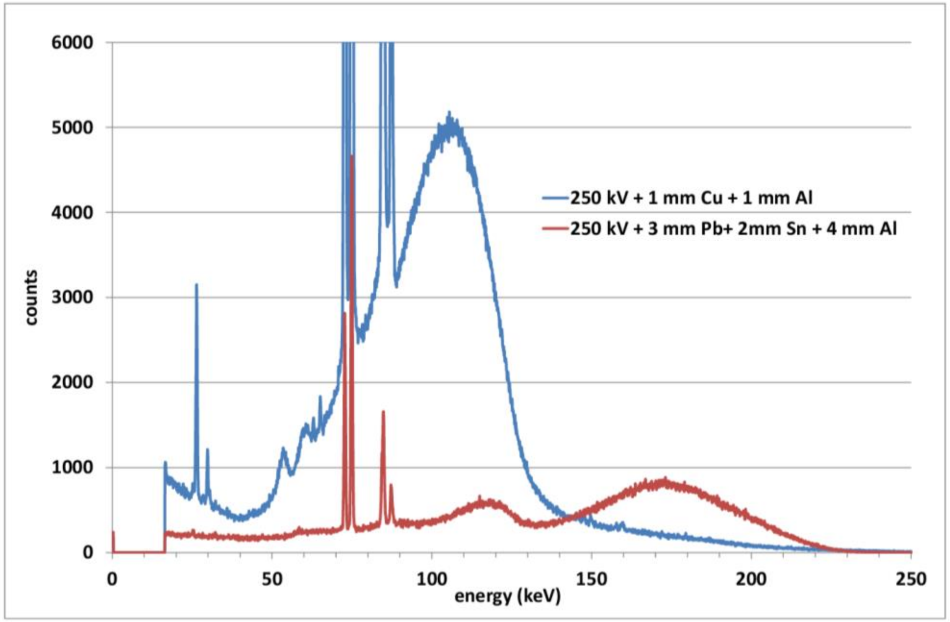
Production principle of X-rays

- X-rays are characterised by:
  - Maximum tube voltage (kV) → maximum photon energy (keV)
  - Total filtration:
    - Inherent tube filtration
    - Additional filtration
  - Average photon energy (keV)
  - Full width at half maximum (FWHM in keV or %)
  - HVL (half value layer in mm Cu or mm Al)

Energies of the particles and the energy respose



Average energy (keV)



- Tube voltage defines the maximum photon energy.
- Filters define the FWHM and absorb ("remove") the low energies from the spectrum.

- Unwanted effect – more filtration -→ smaller dose rates.

Time integrated doses and dose rates

- What dose rates are needed for irradiations of biological samples?
- Some detectors (dosemeters) behave differently at different dose rates (e.g. continous beam and pulsed beam). Similar for biological samples (1 Gy in 1 second ≠ 1 Gy in 10 years).
- The dose rate can be changed by:
  - Sources with different activities
  - Distance from the source – $1/d^2$ dependence.
  - Change the electric current (power) for X-ray generators.
- The total delivered dose = dose rate x time
  - Change dose rate
  - Change time
- **Is dose rate dependence important for your experiment ?**

Size of the samples

- The dosimetric quantities are usually defined at a reference position (in a point).
- For large volume samples corrections may be needed or the **uncertainties are larger**:
  - » many samples in the room and they shield each other,
  - » samples are placed inside a jars or even incubators – the walls of the holder will change the dose rate and the particle energy- **How???**
  - » The dose may be measured with dosemeters during irradiation inside incubators or as close as possible to the sample. **What is the energy???**

Size of the irradiation room

1. Many samples to be irradiated at the same time
2. Particle scattering from the walls, floor, ceiling or other objects
    1. Manageble effect for photons
    2. Difficult to estimate for neutrons – strong energy change

3. Really big samples - incubators

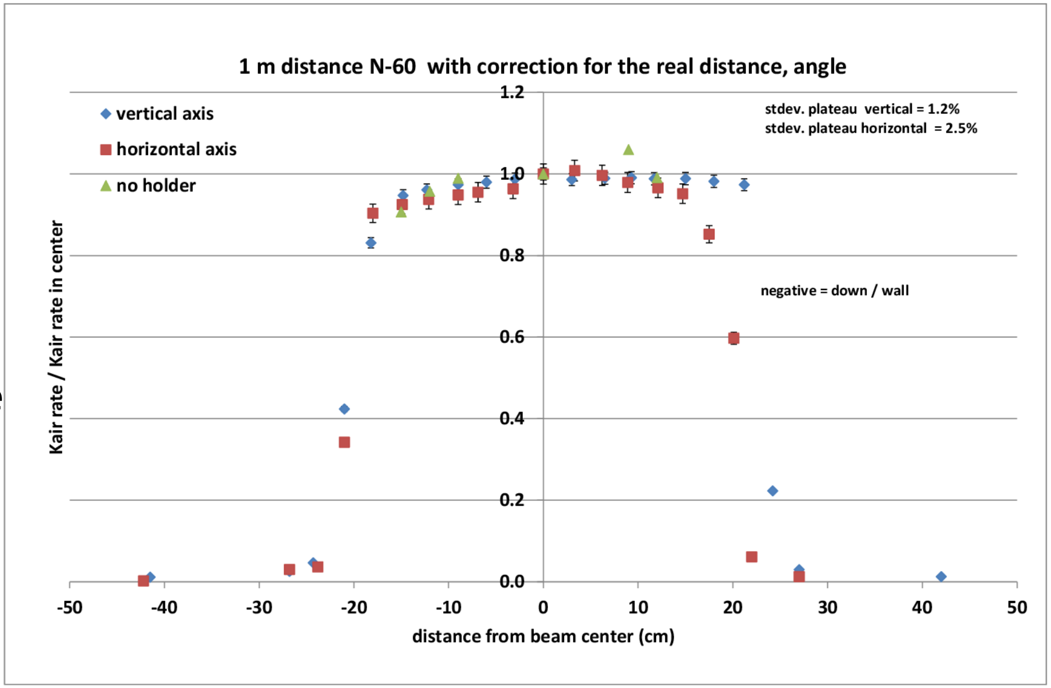
Ambient conditions

- Normal ambient conditions for a dosimetry calibration laboratory are:
  - temperature = 18-22 ^{o}C
  - humidity=20-80 %
  - pressure=86 -106 kPa

- How often special conditions are needed and what:
  - Temperature
  - Humidity
  - Pressure
  - Light – additional light above the samples → ventilation system not adaptated for extra heat → spots with higher temperature around the samples
  - CO_2 content – incubators
  - gravity – rotation of samples → additional objects in the beam

Beam size and beam geometry

- Two types of beams:
  - Collimated:
    - Horizontal or vertical irradiations
    - Typicaly small opening ~ 20 oC – adjustable with different collimators
    - Suitable for small samples
    - Reduced scattering from walls and other objects in the rooms
  - Non–collimated – particles emitted in 4π solid angle:
    - Many samples can be irradieted at the same time
    - Scattering of particles from other objects may be important
- Beam profiles – is the dose rate constant inside the beam spot:



- International normes (only 3 examples):
  - ISO 17025 – General requirements for teh competence of testing and calibration laboratories – ISO 17025 accreditation – **BELAC** logo (in Belgium) on the irradiation certificates
  - ISO 4037 – X and gamma reference radiations for calibrating doseneters and doserate meters and for determining their responce as function of phootn energy
  - ISO 8529 – Reference neutron radiations

- Traceability to the highest metrology standards:
  - Air kerma (Gy) or H*(10) and Hp(10) (Sv) – defined using ionisation chambers and international comparison managed by BIPM (Bureau International de Poid et Measures).
  - **Be sure that 1 Gy is equal 1 Gy in any laboratory in the world !**
  - **Try to irradiate with standard beam qualities (ISO requirements):**
    - » **easier to compare the results with other laboratories**
    - » **less questions**
    - » **changes in metrology standards and differences between laboratories can be traced back if needed.**

Uncertainty budgets

- Detailed analysis of the uncetaities involed in the experiment
- ISO 17025 laboratories are required to provide :
  - the the uncertainty of the measured quantity (dose rate) on each certificate
  - a detailed uncertainty budget if the customer needs it
- GUM – Evaluation of measurement data – Guide to the expression of uncertainty in measurement
- Uncertainties correlations ?
  - Example: - measure 10 times a distance but we the same ruler – only one calibration coefficient
  - Presently many experiments do not need a evaluation of the correlation between uncertainties and generation of covariance matrices. If better uncertaintie will be needed in the futures such covariance (correlation) data will also be needed.

Conclusions

- The uncertainties on the dose delivered to the bilogical samples can be improved if following parameters are under controlled:
  - ambinet conditions (t, p, H, light, air content...) during irradiations
  - scattering of radiation from objects in the beam or from sample holders,
  - sample size,
  - distance from the laboratory to the irradiation facility and transport conditions,
  - traceability of the dose measurements (also t, p, H,...) to international standards.

- Advertisement: Laboratory for Nuclear Calibrations (LNK) of SCK•CEN;
  - nuclearcalibrations@sckcen.be
  - www.sckcen.be