Miniaturized BeO-OSL detectors for dosimetry in cell cultures and organisms: Applicability and challenges

Diploma thesis
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Overview

1. About the problem
2. Dosimetry with the probe method
3. The dosimetry system
4. Applicability in different environments
5. Effects of modifying the dosimetry system
6. Further results and outlook

About the problem

Advantages of small dosimeters:

- allow dose measurements at one defined point, also in very inhomogenous environments
- smaller perturbation of the radiation field (and of the dose distribution)
- match the typical size of cell cultures and small organisms (≤ 1 mm)

About the problem

But:

- small detectors are difficult to handle – and probably also to find after application in an organism
- detectors have to remain inert in biological environments
- new questions about the analyzation method (a very low signal level is expected)

Dosimetry with the probe method

Almost impossible to get a dose value directly from biological tissue (e.g. by analyzing damaged proteins, chemical changes or increased temperature).

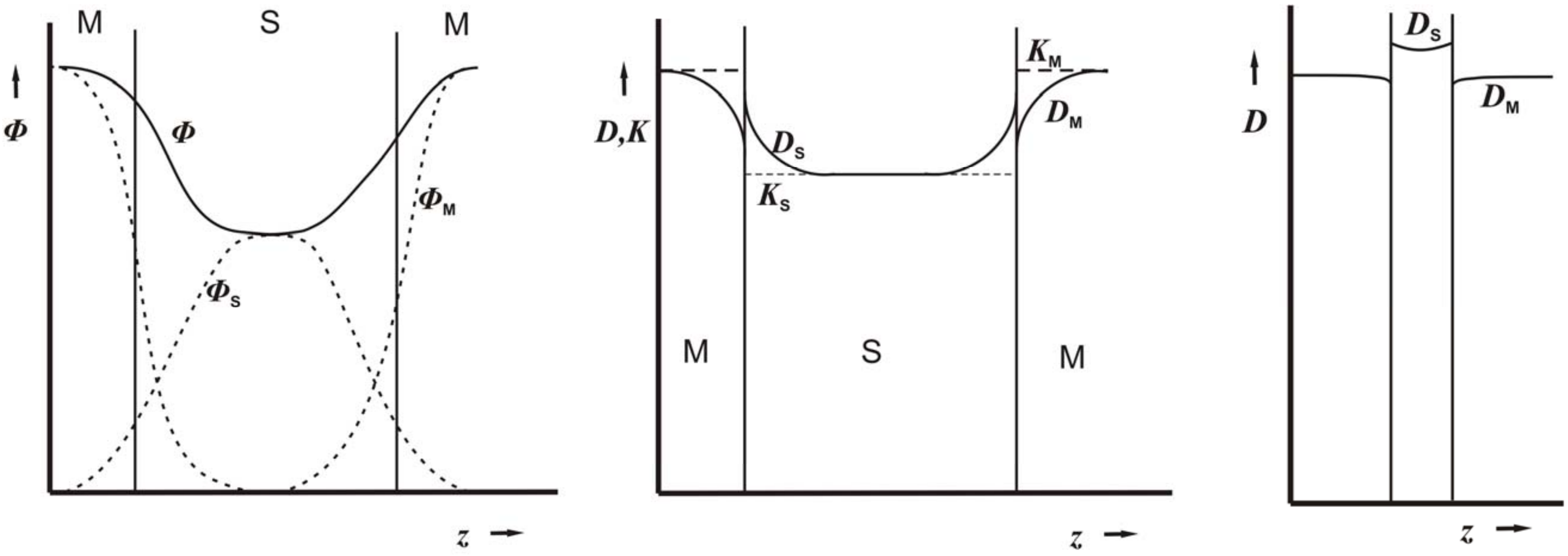
→ Idea: Replace local tissue with a material, where an easy measurable value is proportional to the applied dose

Examples:
- increasing optical density of a film
- light emitted by scintillating materials
- luminescence light of materials like LiF, Al_2O_3, BeO
- electric current in an ionisation chamber

Dosimetry with the probe method

But: Probe material has different interaction with radiation field because of different interaction coefficients

→ leads to different dose values!



Dosimetry with the probe method

Possible solution: Theory of ideal probes –
avoiding or keeping the dose gradient outside the probe

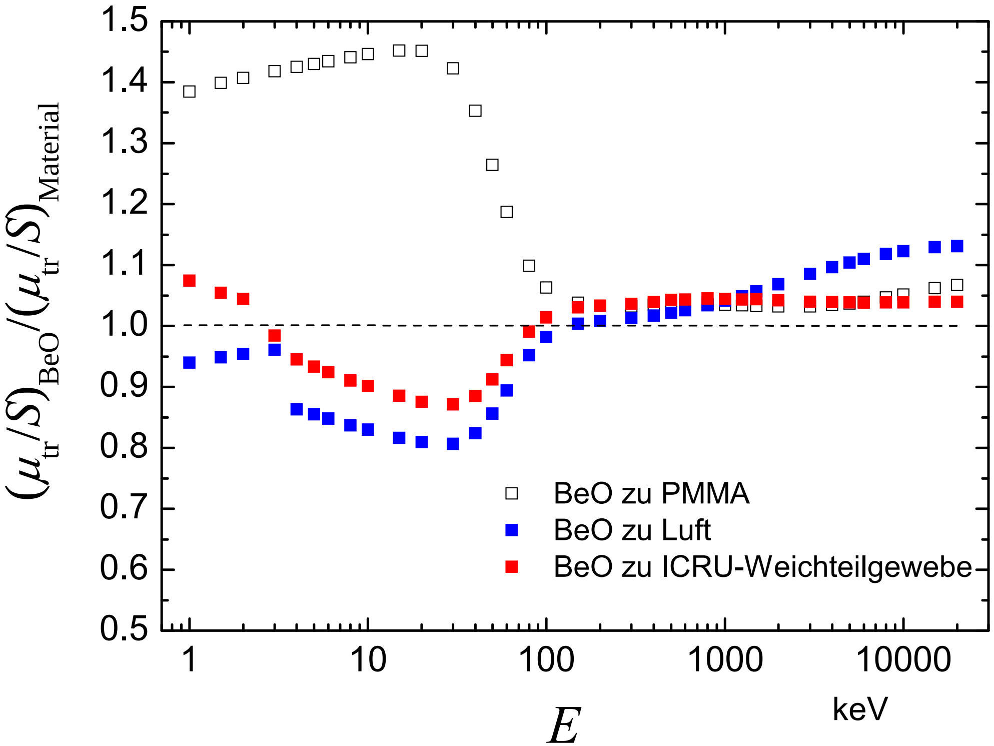
Equilibrium probes:
- shouldn‘t affect the primary radiation field noticeably (have to be small!)
- require a secondary electron equilibrium within the whole probe volume
- only the field of primary photons determine the energy dose

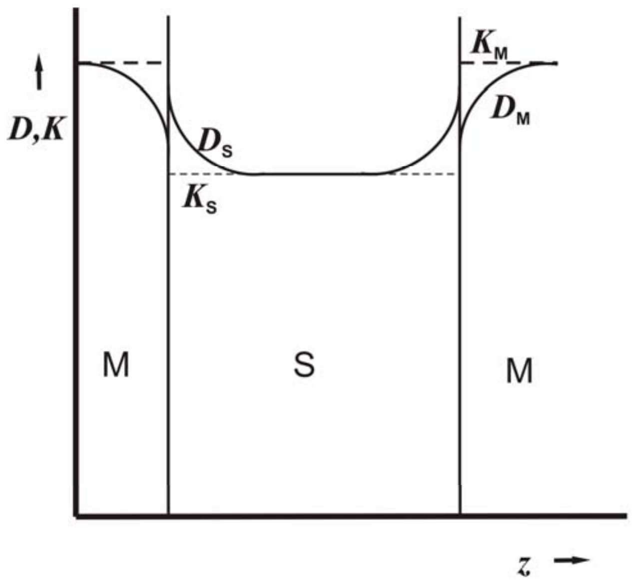
Equilibrium probes are not usable for electron radiation, but are very good photon dose detectors.

Dosimetry with the probe method

How to provide a secondary electron equilibrium within the whole probe volume?

- Find an equivalent probe wall material!





Dosimetry with the probe method

How to calculate the energy dose value in the original material?

Same radiation field – same fluence, different interaction coefficients lead to

$$D_{\mathrm{B}} = \frac{\left(\overline{\mu}_{\mathrm{tr}} / \rho\right)_{\mathrm{B}}}{\left(\overline{\mu}_{\mathrm{tr}} / \rho\right)_{\mathrm{A}}} D_{\mathrm{A}}$$

(D_{A} is the probe dose value)

Similar approach for electron radiation (Bragg-Gray-Theory)

- thin probes to avoid affection of primary electron field
- very thin wall to keep secondary generation electrons out

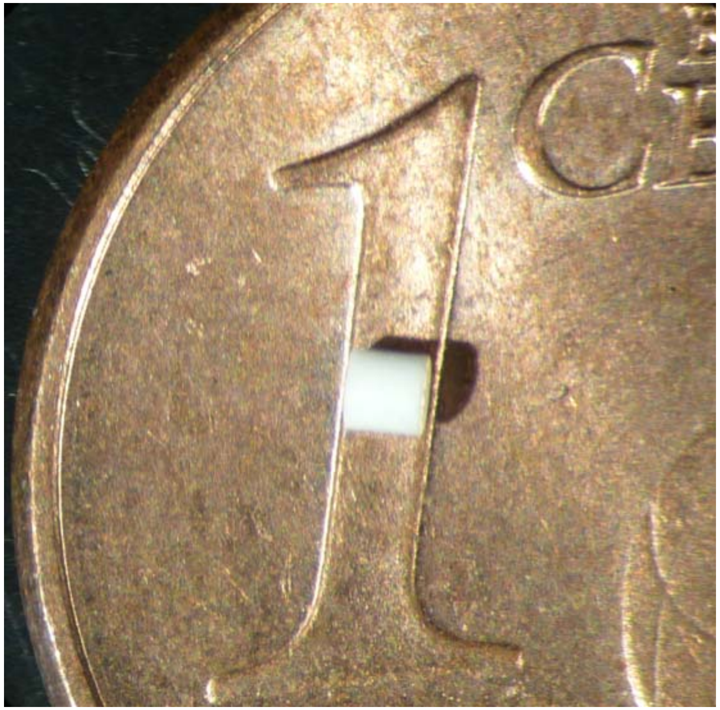
→ Probe is a pure electron dose detector, then:

$$D_{\mathrm{B}} = \frac{\left(\overline{S}/\rho\right)_{\mathrm{B}}^{\mathrm{col}}}{\left(\overline{S}/\rho\right)_{\mathrm{A}}^{\mathrm{col}}} D_{\mathrm{A}}$$

The dosimetry system

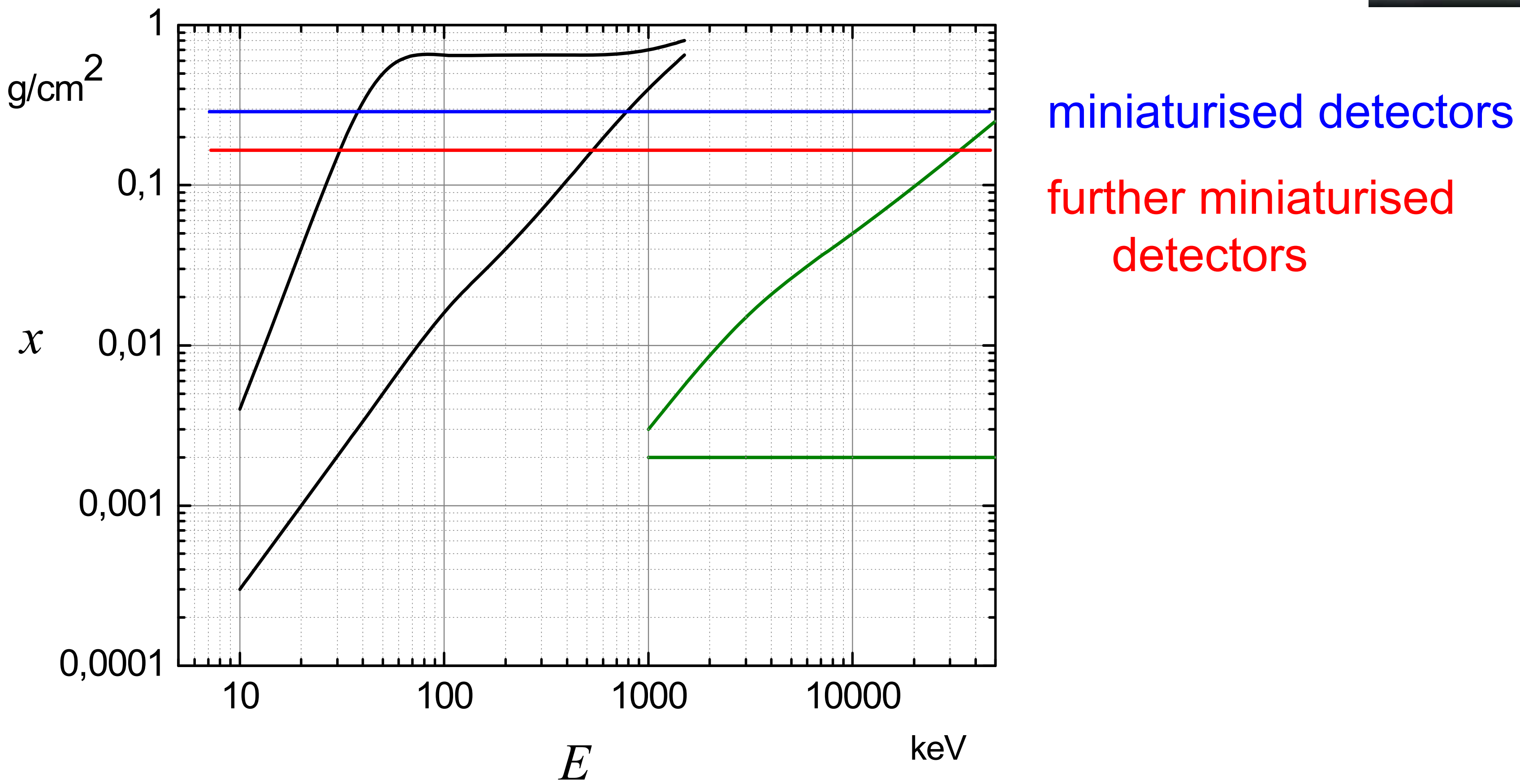
to be tested: miniaturized BeO-detectors (1 mm height and diameter)

- sintered from BeO powder
- density about 2.85 g/cm³
- very stable and hard (9 at Mohs scale)
- insoluble in water
- melting point about 2530 °C
- electric isolator
- effective atomic number of 7.12



- have property of optical stimulated luminescence

The dosimetry system



Need for specific calibration in some radiation fields because detectors won‘t be ideal probes!

The dosimetry system

Why can BeO be used as dosimetric detector material?

- property of optically stimulated luminescence (OSL) with a dose – proportional measurement effect

- easy measurable value (UV light emission)

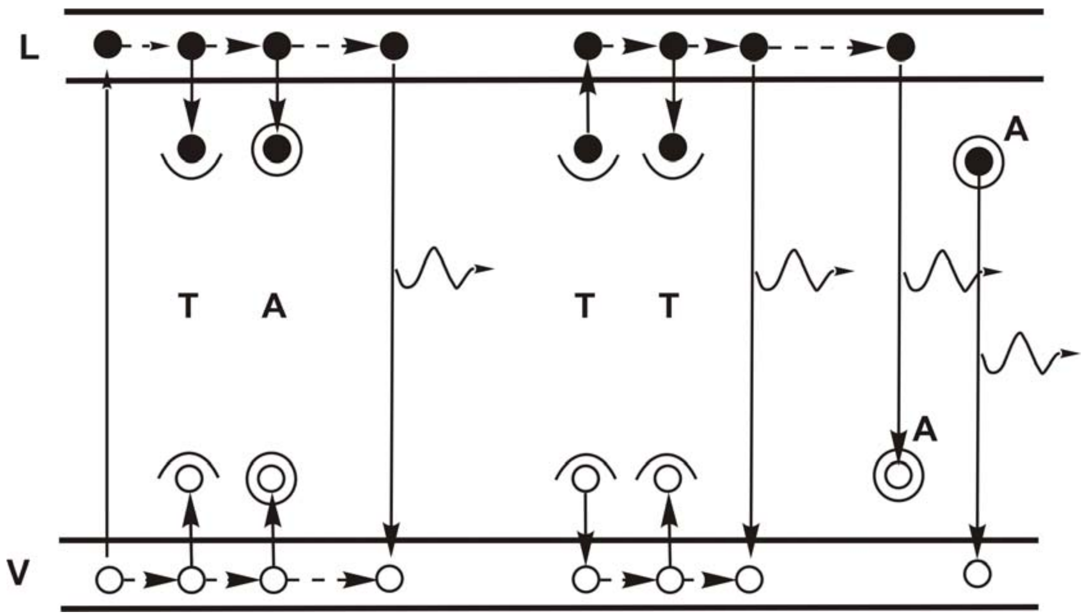
- material is reusable many times after deleting the energy dose

- effective atomic number of 7.12 is similar to effective atomic numbers of biological materials
  muscle: 7.64 water: 7.51 adipose: 6.46 air: 7.78

The dosimetry system

Optically stimulated luminescence:

Lattice defects and impurities produce additional energy levels, some of them with very long electron storage periods.



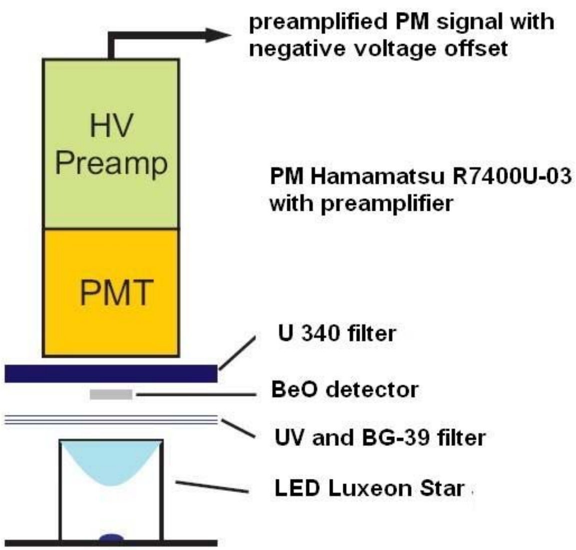
model to describe stimulated luminescence

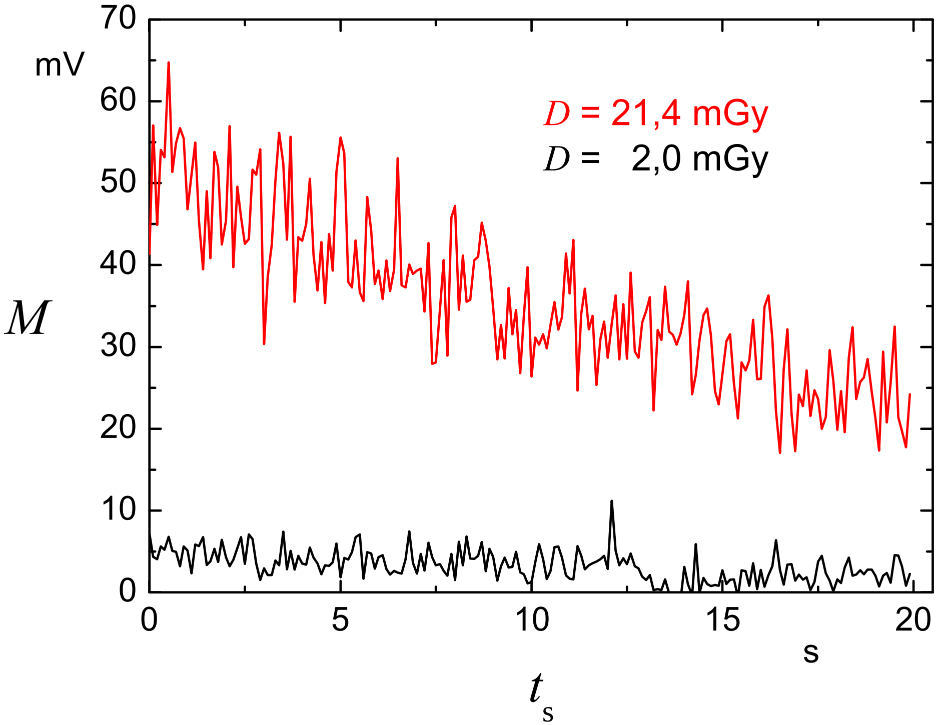
The dosimetry system

How to collect the emitted light?

BeO*max* system, developed at the Radiation Physics Group

The dosimetry system





The dosimetry system

Problem: background signal – sources:

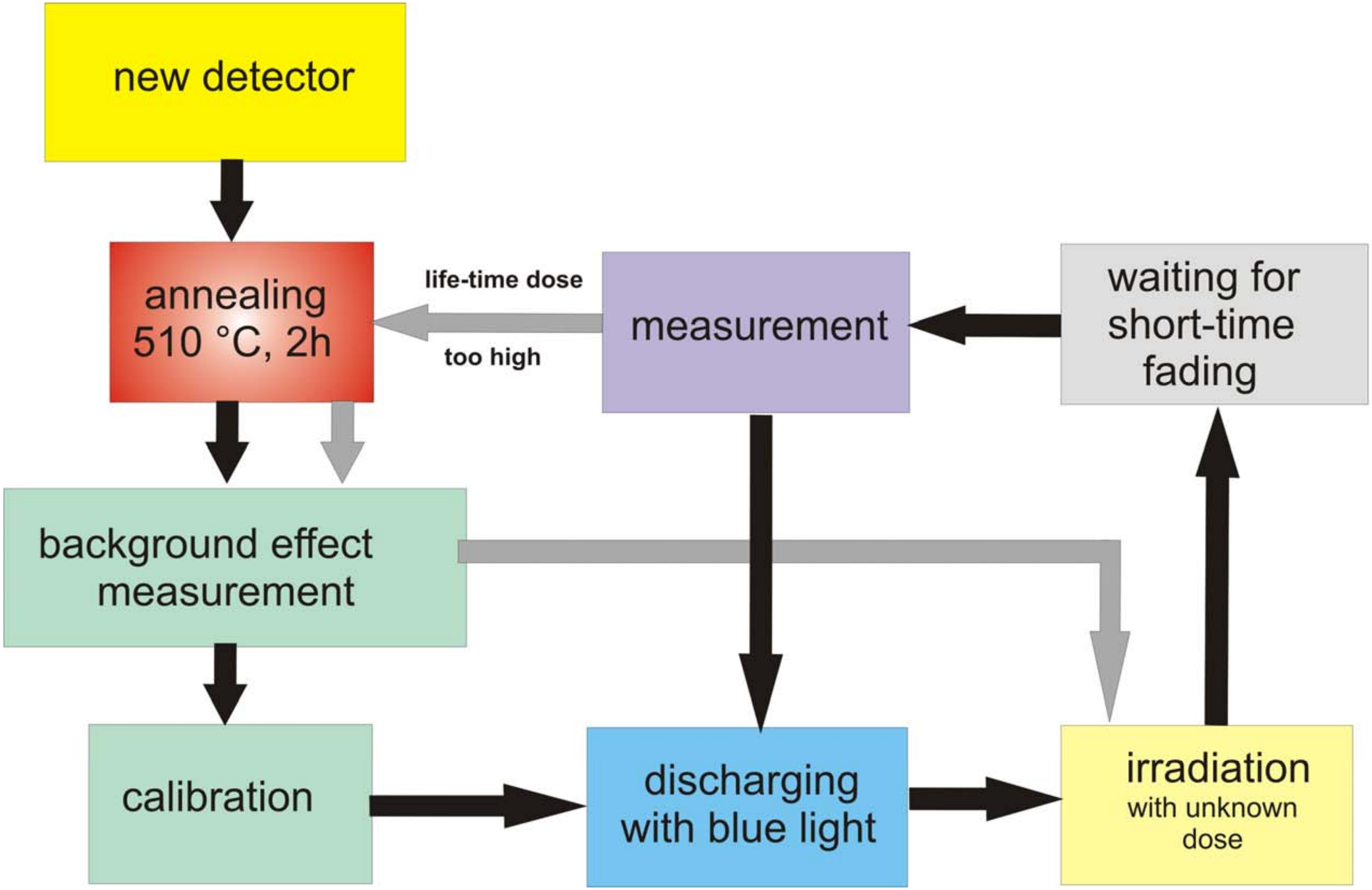
- changing preamplifier offset
- preamplifier noise
- background radiation

→ leads to a lowest measurable dose of 0.4 mGy
(100 measurements of the background effect)

Problem: every BeO detector has its own sensitivity
→ every detector has to be calibrated individually

Problem: short-time fading after irradiation (10% within 30 minutes)
→ detectors have to remain in a dark environment between irradiation and measurement

The dosimetry system



Applicability in different environments

Detectors have to remain inert in:

- water and aqueous solutions
- acids and bases
- organic solvents
- bodily liquids
- culture mediums used for cell growth

Results after treatment of detectors with a lot of substances:
Detectors are inert, even in hot concentrated acids (except hydroflouric acid) and don‘t change their sensitivity.

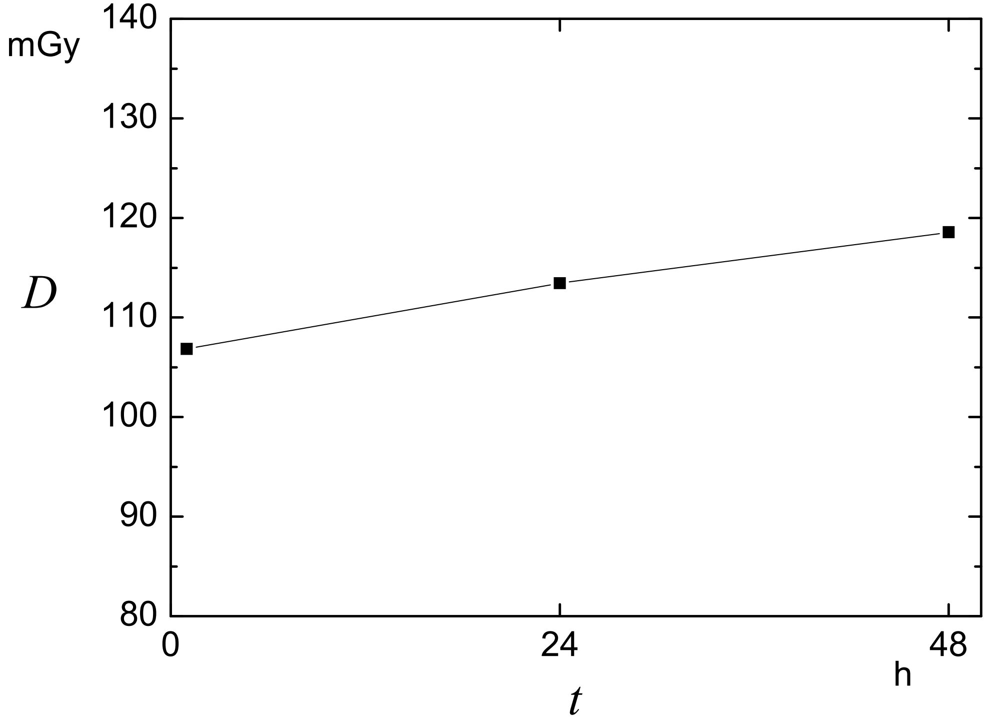
Test for applicability in radioactive solutions:

Applicability in different environments

Irradiation of detectors in 90 ml of a solution containing 1 GBq of ^{90}Y

Applicability in different environments

Increasing detector dose because of detector surface contamination!



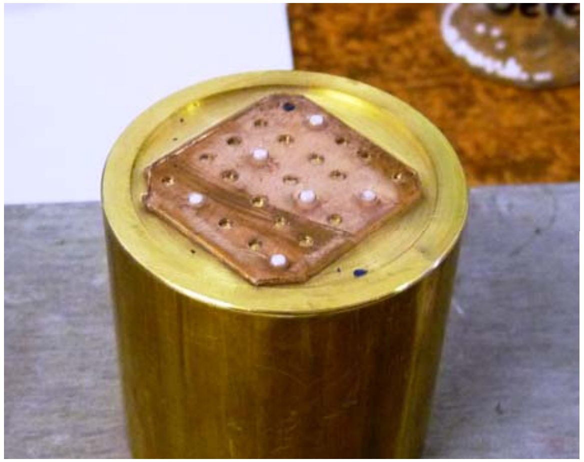
Effects of modifying the dosimetry system

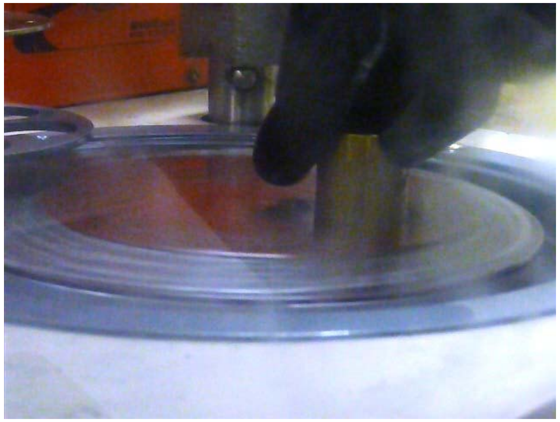
1. Decreasing detector size

BeO powder is highly cancerogen when inhalated!

→ Grinding of the detectors to reduce their size must be done under safety precautions!

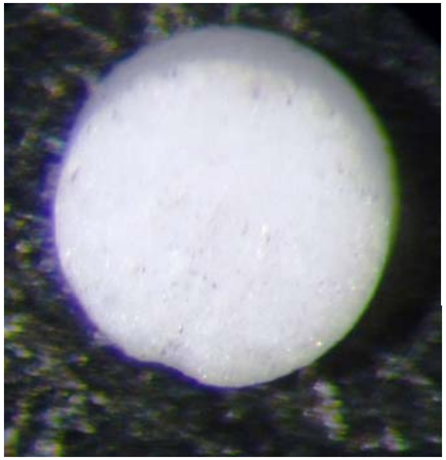
Partner: Karlsruhe Beryllium Handling Facility

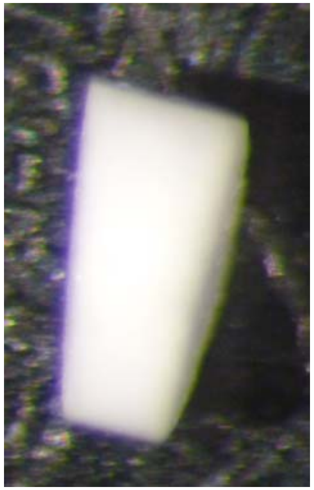




Effects of modifying the dosimetry system

Result:



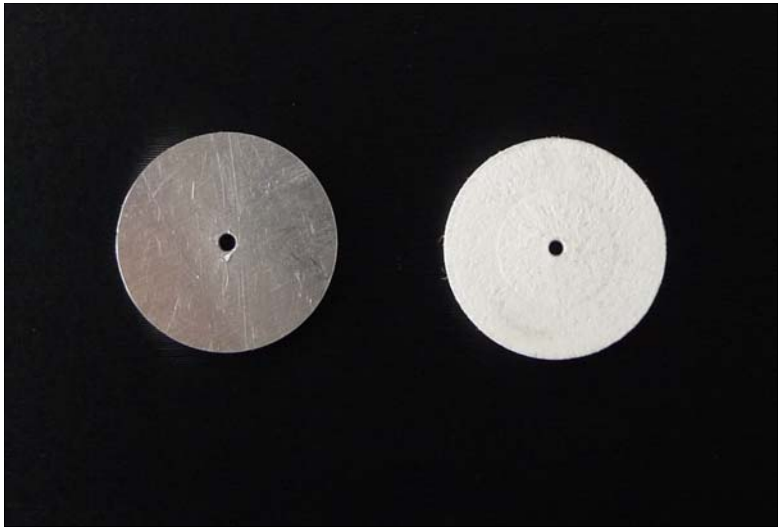


- reduced height of about 57%
- slightly increased lowest measurable dose (0.6 mGy)
- very difficult to handle

Effects of modifying the dosimetry system

2. Changing surrounding material during measurement

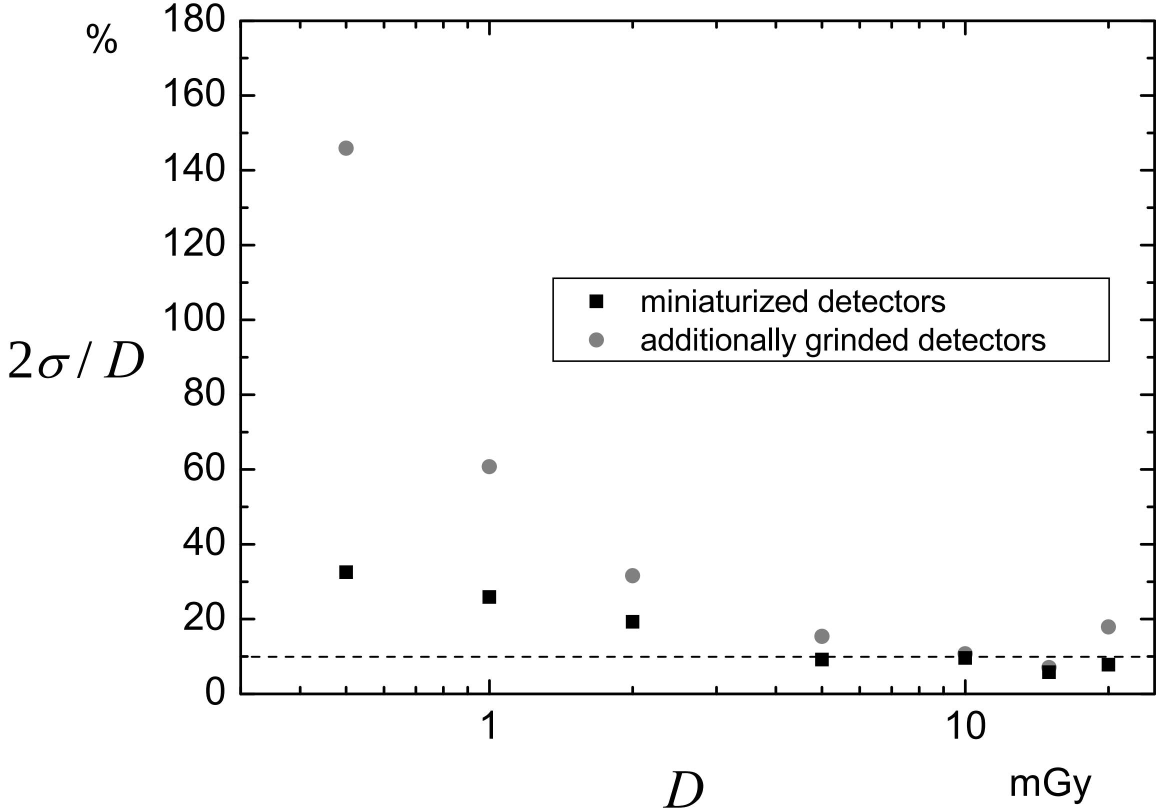
When using aluminium, only the bottom of the detector is stimulated
→ An opaque material allows additional stimulation of the detector side



Aluminium and Optisol, an opaque Teflon-based polymer

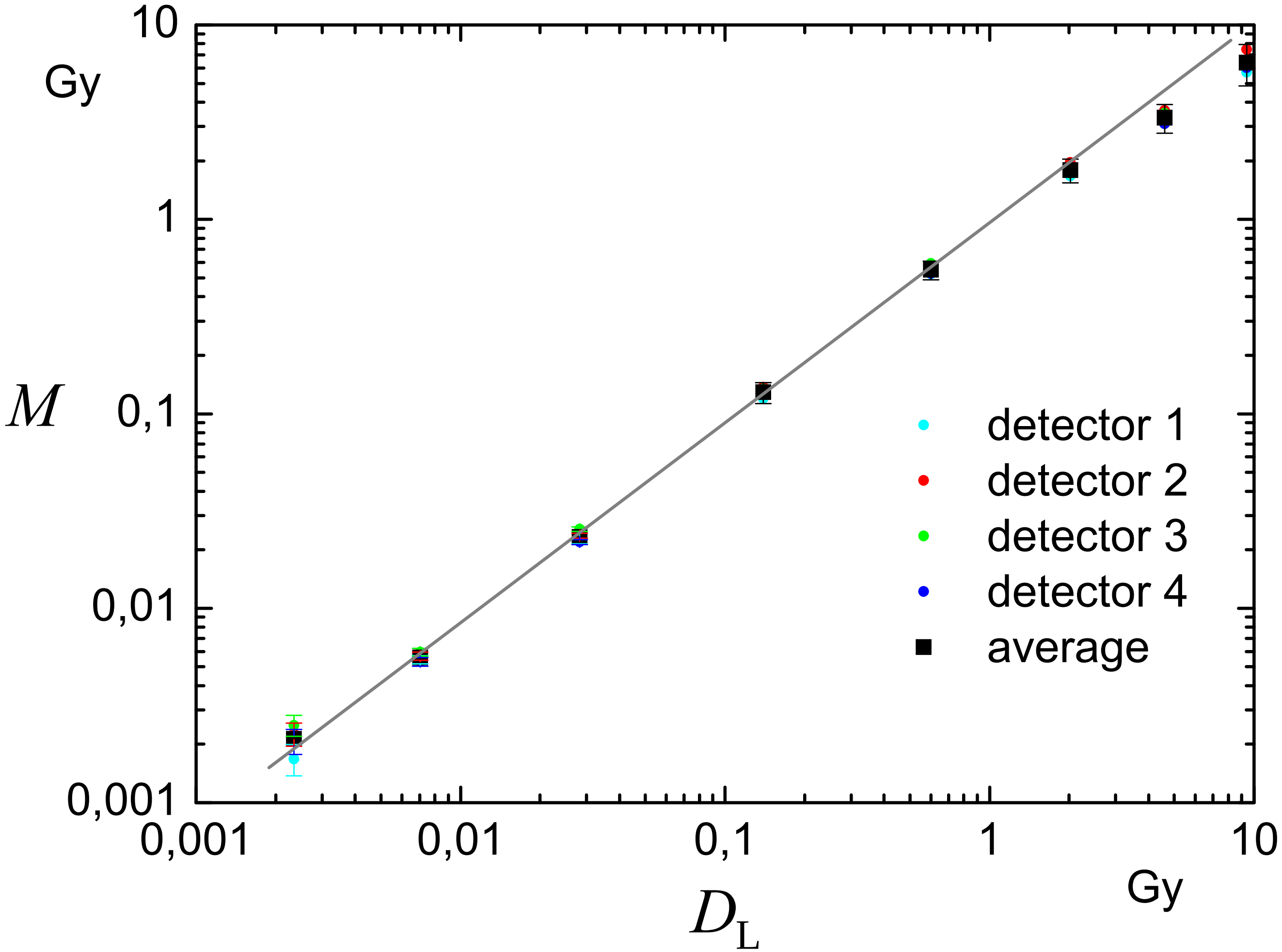
Effects of modifying the dosimetry system

Result:
- increased sensitivity (about 50%)
- decreased lowest measurable dose (below 0.3 mGy)
- improved measurement repeatability



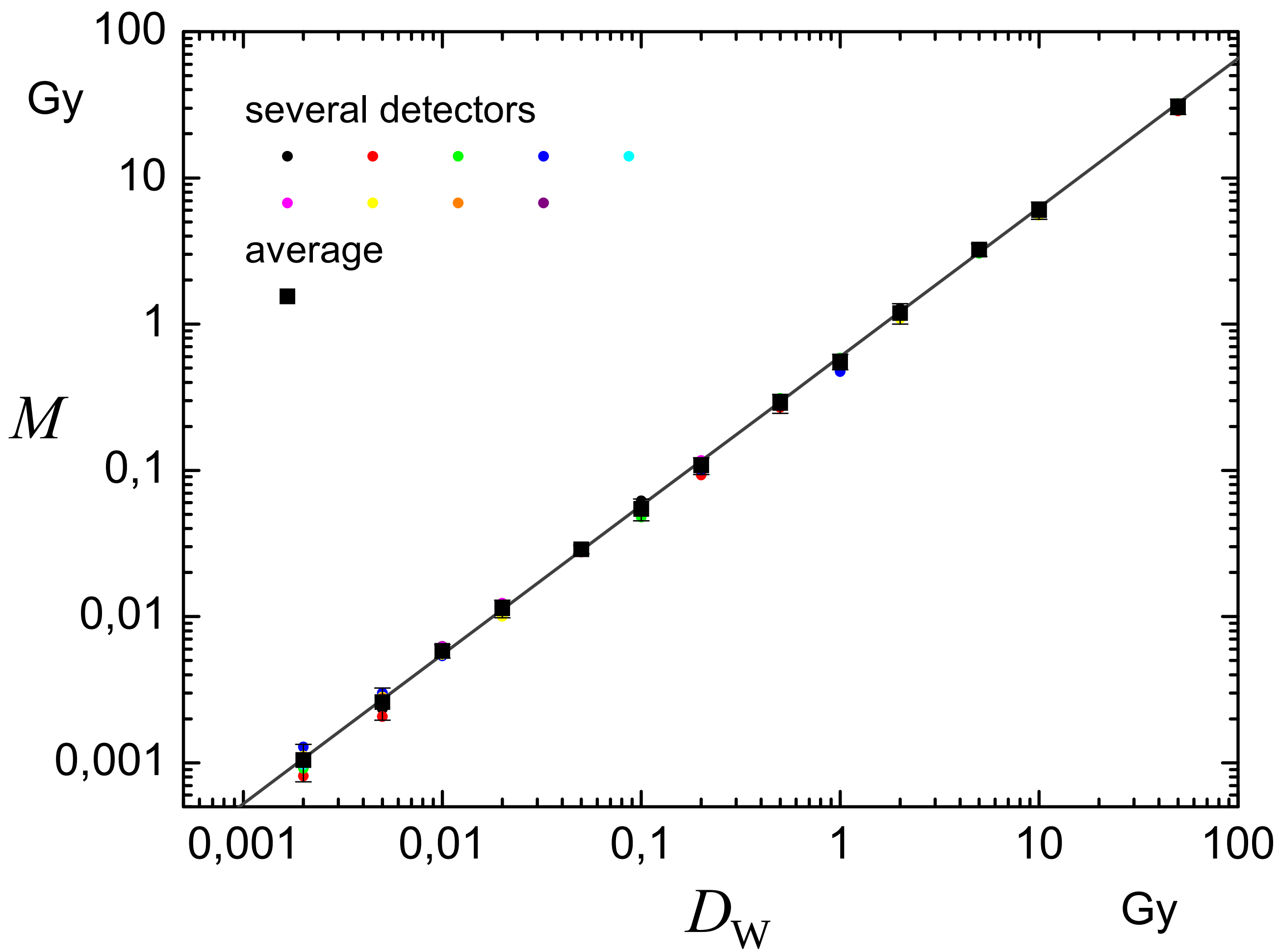
Further results and outlook

Dose characteristic: photon irradiation (662 keV of ^{137}Cs)



Further results and outlook

Dose characteristic: beta irradiation (^{90}Y)



Further results and outlook

Done:
- characterisation of the dosimetry system consisting of miniaturised BeO-detectors and the BeO*max* device
- detectors can be used in biological and radioactive environments
- knowledge about application and reusability
- link to dosimetry theory to avoid wrong dose values

To do:
- using a photon counter instead of a photo multiplier tube to improve sensitivity and to decrease the lowest measurable dose
- improved stimulation unit
- effects of an even further miniaturisation?
- research on use of the detectors in bright environments

Thank you for your attention!

Laboratory
Underground
Nuclear
Astrophysics

The LUNA experiment

at the Gran Sasso Laboratory in Italy

Michael Anders

Forschungszentrum
Dresden-Rossendorf

Nuclear Astrophysics research at LNGS

LUNA…

… is a collaboration of several institutions in Italy, Germany and Hungary (about 25 people)

… is the world‘s only deep underground experiment using an accelerator

… has successfully measured data of important reactions of primordial and nucleosynthesis in stars

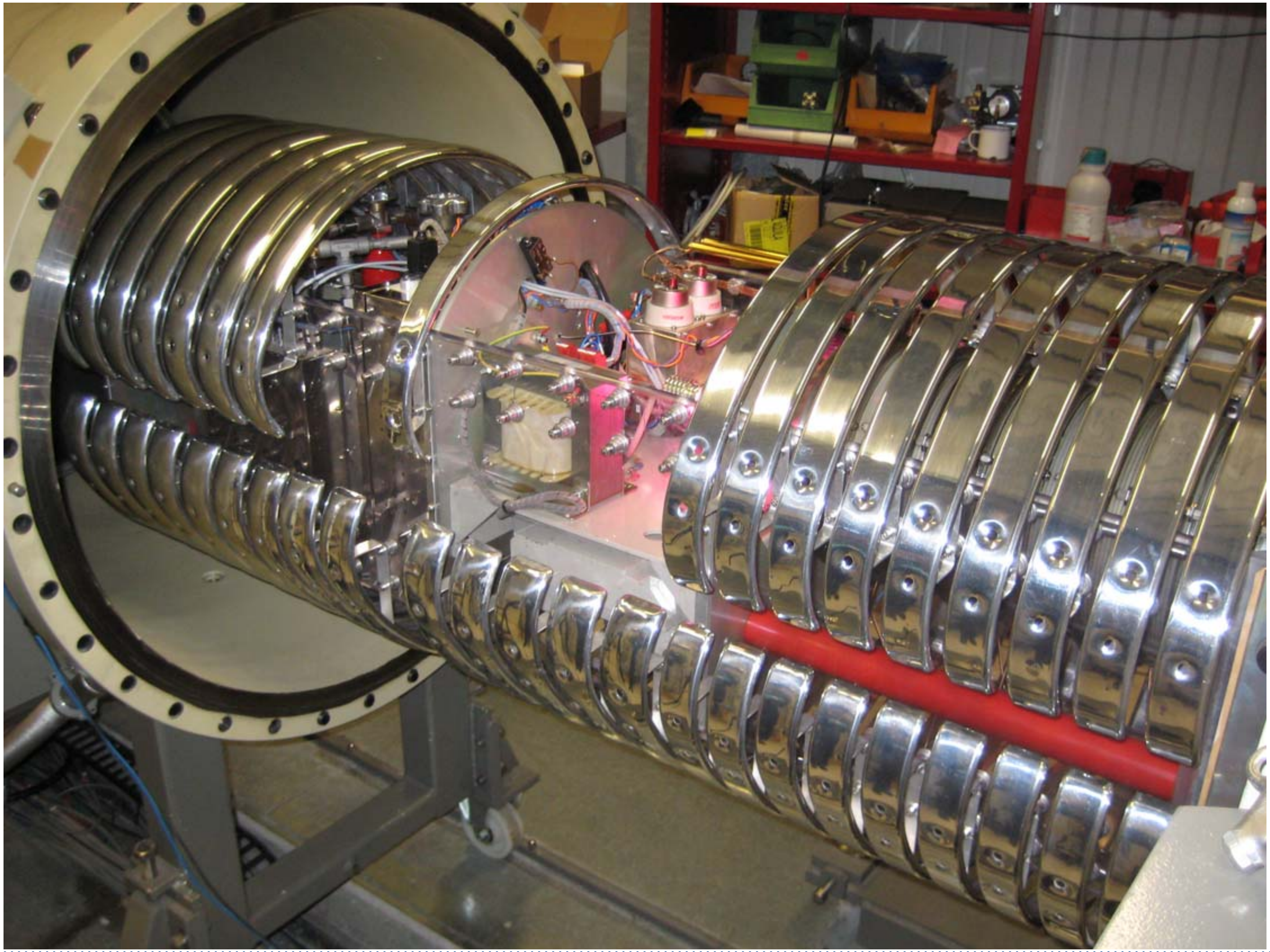
… uses now a 400 kV linear ion accelerator

„My“ experiment is the $^{2}_{1}\mathrm{H} + ^{4}_{2}\mathrm{He} \rightarrow ^{6}_{3}\mathrm{Li} + \gamma$ reaction…

The challenges of Nuclear Astrophysics

…at energies below the Coulomb barrier, so with very low cross sections. Measuring them is sometimes like…

The LUNA 400 kV accelerator



The shielded gas target setup

Thank you again for your attention!