Institute of radiation physics, Switzerland

Dosimetry verification for FLASH radiotherapy

C. Bailat,

T. Buchillier, P. Jorge,

K. Petersson, M. Jaccard, R. Möckli, D. Patin, M. Gondré
F. Bochud, J-F. Germond, L. Desorgher, P. Froidevaux
J. Damet, N. Cherbuin

- one of five university hospitals.
- Connected to the biology and medicine department of UNIL
- Over 11’000 employees
- Over half a million annual hospitalization-days.

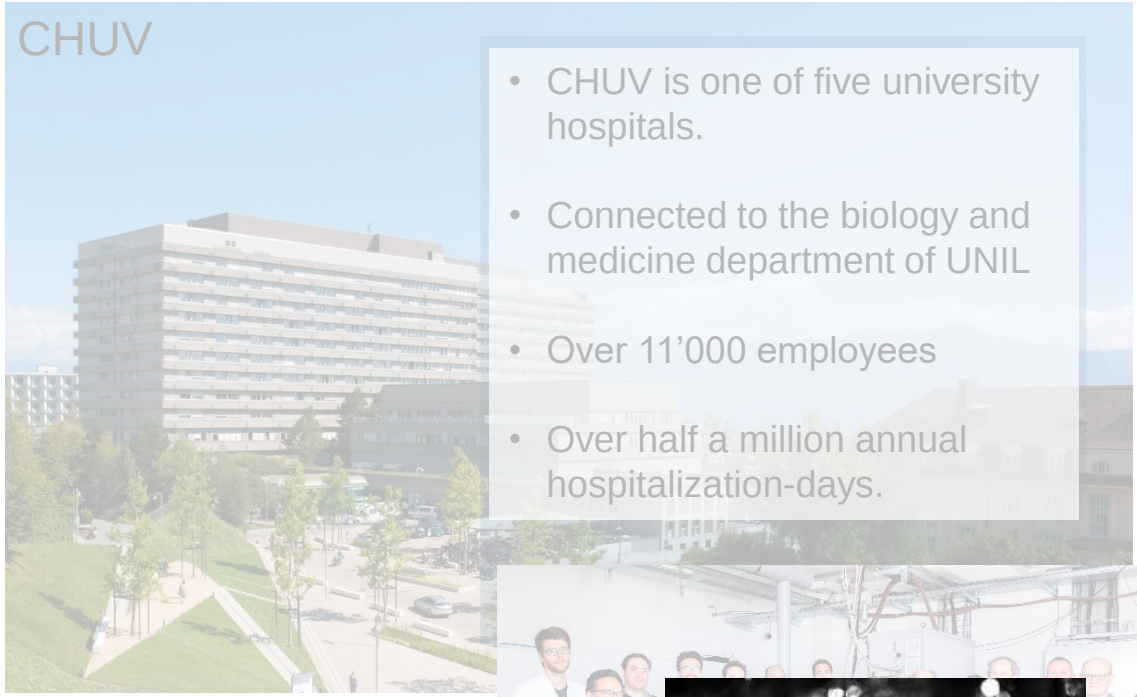
Institute of Radiation Physics (IRA)

IRA: ~60 Collaborators

IRA provides expertise in:

- **Medical physics**
- **Radiation protection**
- **Radiochemistry**
- **Radiopharmacy**
- **Radiometrology**

CHUV



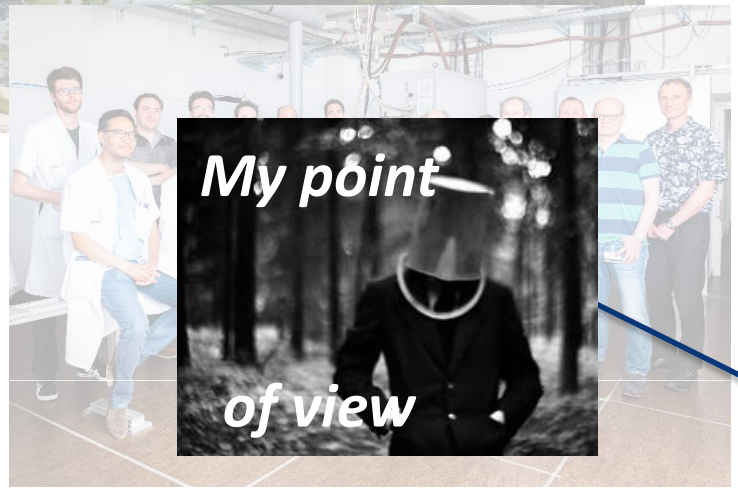
- CHUV is one of five university hospitals.
- Connected to the biology and medicine department of UNIL
- Over 11’000 employees
- Over half a million annual hospitalization-days.

Institute of Radiation Physics (IRA)

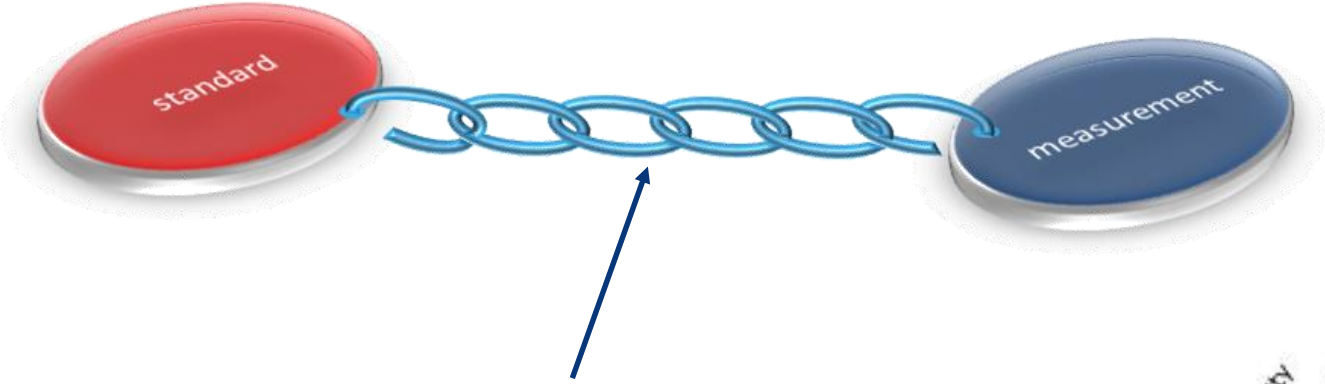
IRA: ~60 Collaborators

IRA provides expertise in:

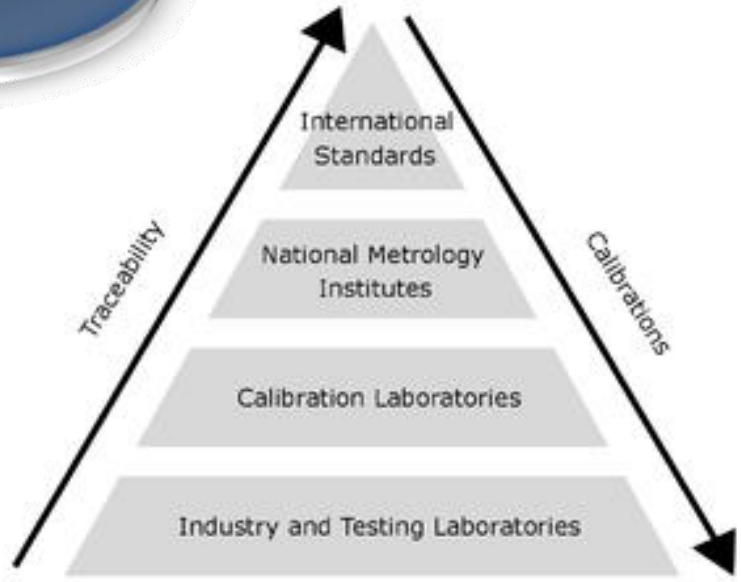
- **Medical physics**
- **Radiation protection**
- **Radiochemistry**
- **Radiopharmacy**
- **Radiometrology**



METROLOGY is obsessed with **Traceability**



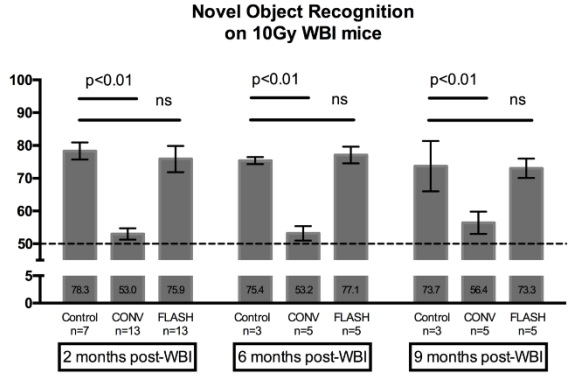
traceability refers to an unbroken chain of comparisons relating an instrument's measurements to a known standard.



FLASH-RT in short: Irradiation at ultra high dose-rate increases the differential response between normal and tumour tissue

Flash

Conventional

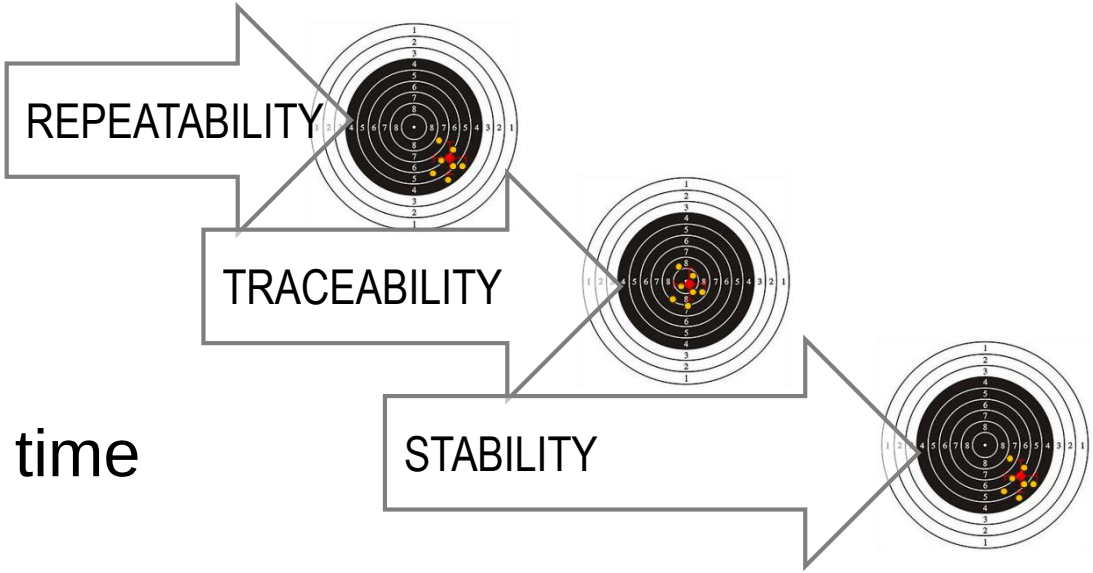


canton de vaud

Our Goals for a safe use of FLASH-RT:

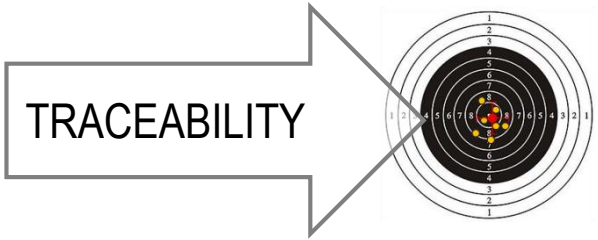
Ensure a **reliable** and **accurate** dose delivery

- Reliable
- Accurate
- Reproducible vs time



Ensure a **reliable** and a**ccurate** dose delivery

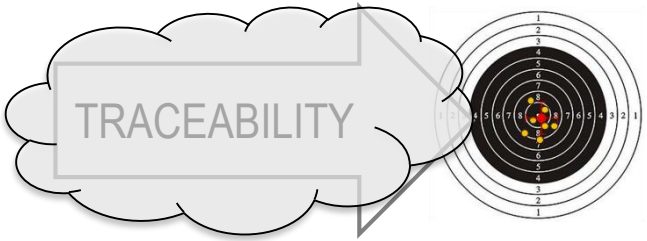
- Reliable
- Accurate
- Reproducible vs time



→ **Agreement accross various locations**

Ensure a **reliable** and a**ccurate** dose delivery

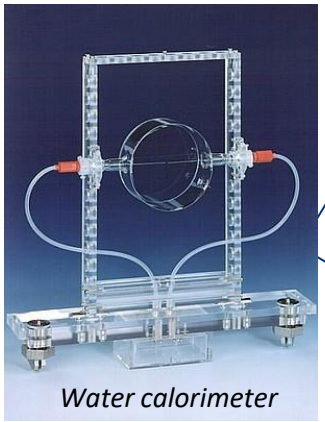
- Reliable
- Accurate
- Reproducible vs time



- Beam is not **standard** (dose rate, field size, …)
  → no primary standard, no commissioning protocol, etc etc etc!!!

- Need to adapt our methodology established using conventional LINACs.

Primary standard



Water calorimeter

traceability

→ Uncertainty budget

Cont.	High energy XR	High energy electrons	Brachy therapy
1	0.9 %	1.0 %	1.0 %
2	1.1 %	1.1 %	1.4 %
3	1.7 %	1.4 %	1.7 %
4	2.9 %	n.a.	n.a.
5	3.0 %	2.1 %	11.5 %
6	2.0 %	n.a.	n.a.
Total	**5.0 %**	**3.1 %**	**12 %**

We are not there yet for FLASH-RT

But we are walking there ….

….. metrologist don’t run

EMPIR project UHDpulse

“Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates”

Andreas Schüller

Department 6.2 “Dosimetry for Radiation Therapy and Diagnostic Radiology”

canton de vaud

EMPIR Call:	2018 / Health
Type:	Joint Research Project
Duration:	2019-2022
Start:	1. Sept. 2019
Funding:	2.1 M €
Coordinator:	Andreas Schüller (PTB)
Topic:	tools for traceable dose measurements for:

- **FLASH radiotherapy**
- VHEE radiotherapy
- laser driven medical accelerators

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

The European Metrology Programme for Innovation and Research (EMPIR):

- metrology-focused programme of coordinated R&D
- enables European metrology institutes, industrial and medical organisations, and academia to collaborate on a wide variety of joint research projects

EMPIR project UHDpulse - Consortium

5 National Metrology Institutes
leading in the field of dosimetry

2 academic hospitals
pioneers in FLASH-RT

3 universities
experts in detector development
pioneer in laser-driven beams

3 national research institutes
pioneer in detector development
pioneer in laser-driven beams
dosimetry expert

1 European research institute
laser-driven beam research

2 companies
expert in detector development

NMI's

PTB — WP6 (coordin.)

NPL National Physical Laboratory — WP1

METAS — WP2

CMI Czech Metrology Institute — WP5 (impact)

Central Office of Measures

Irradiation facility provider

CHUV Centre hospitalier universitaire vaudois — WP3

institutCurie

eli beamlines

Nuclear Physics Institute of the CAS public research institution

Queen's University Belfast

HZDR Helmholtz Zentrum Dresden Rossendorf

Radiation detector developer

ADVACAM Imaging the Unseen — WP4

CSIC

CNM

USC Universidade de Santiago de Compostela

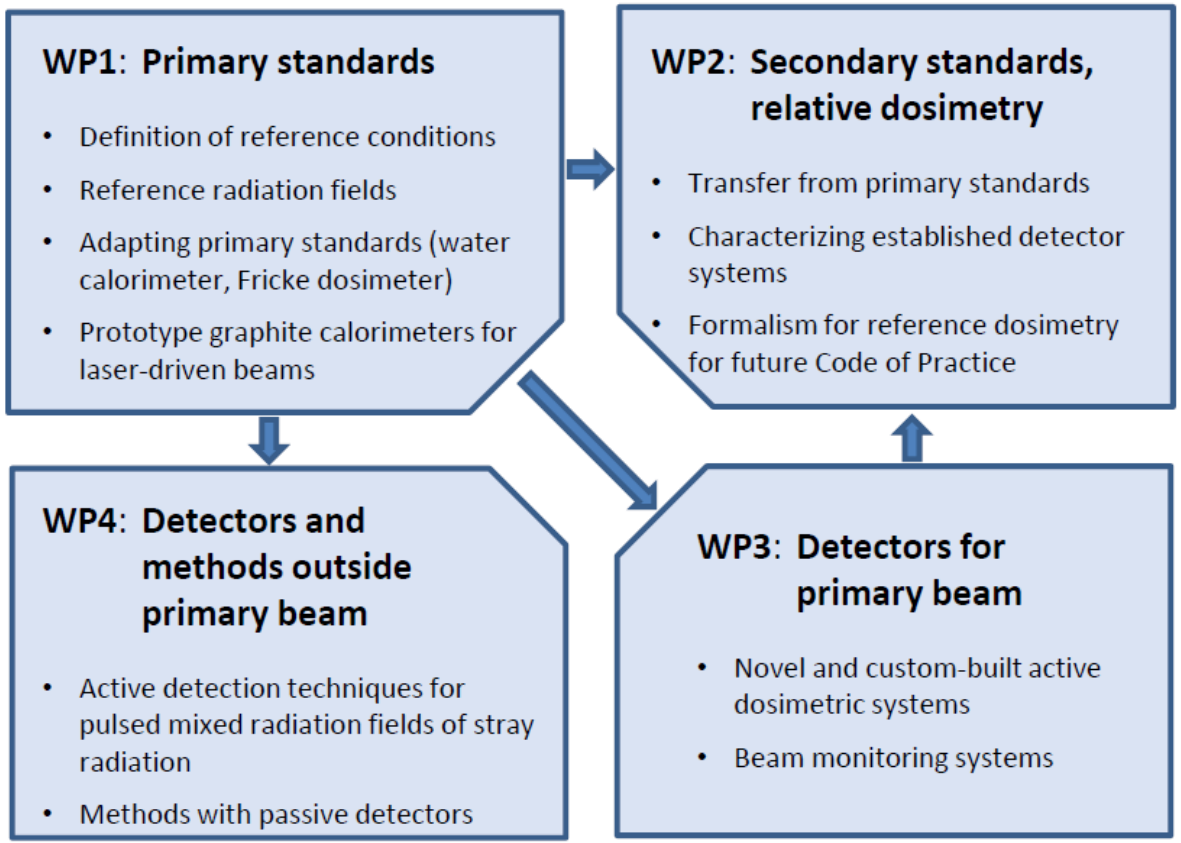
Politecnico Milano 1863

PTW The Dosimetry Company

canton de vaud

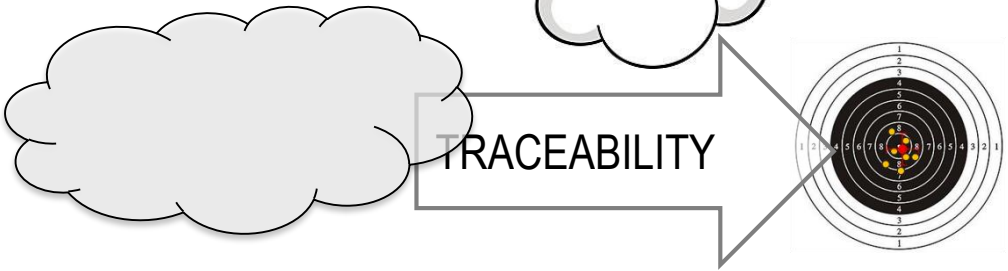
CHUV

UHDpulse - Work Package Structure

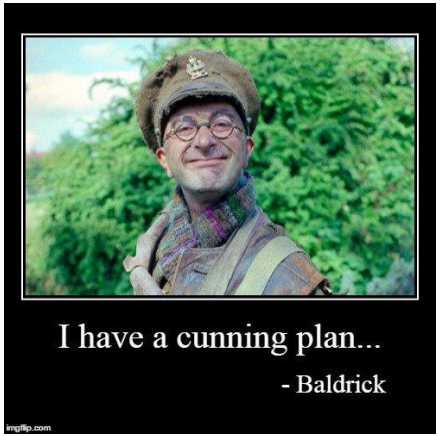


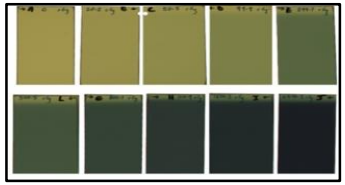
Ensure a **reliable** and a**ccurate** dose delivery

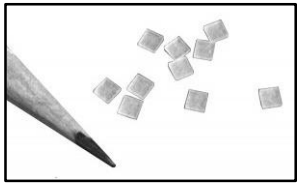
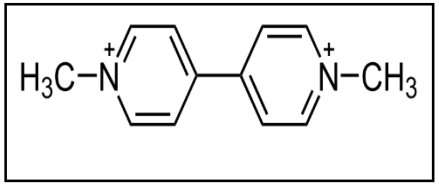
- Reliable
- Accurate
- Reproducible vs time



In the mean time, we went for a cunning plan….

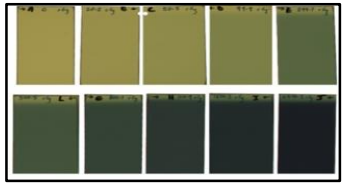


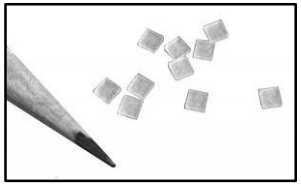
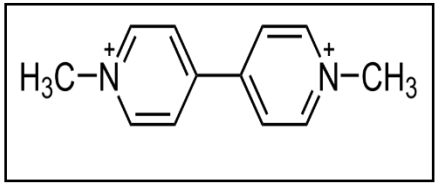


Five different dosimeters:

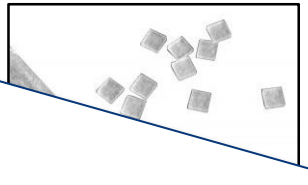
- Films
- Ionization chamber
- Thermoluminescent dosimeter (TLD)
- Methyl viologen
- Alanine

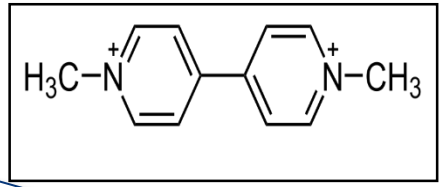


Five different dosimeters:

- Films
- Ionization chamber
- Thermoluminescent dosimeter (TLD)
- Methyl viologen
- Alanine





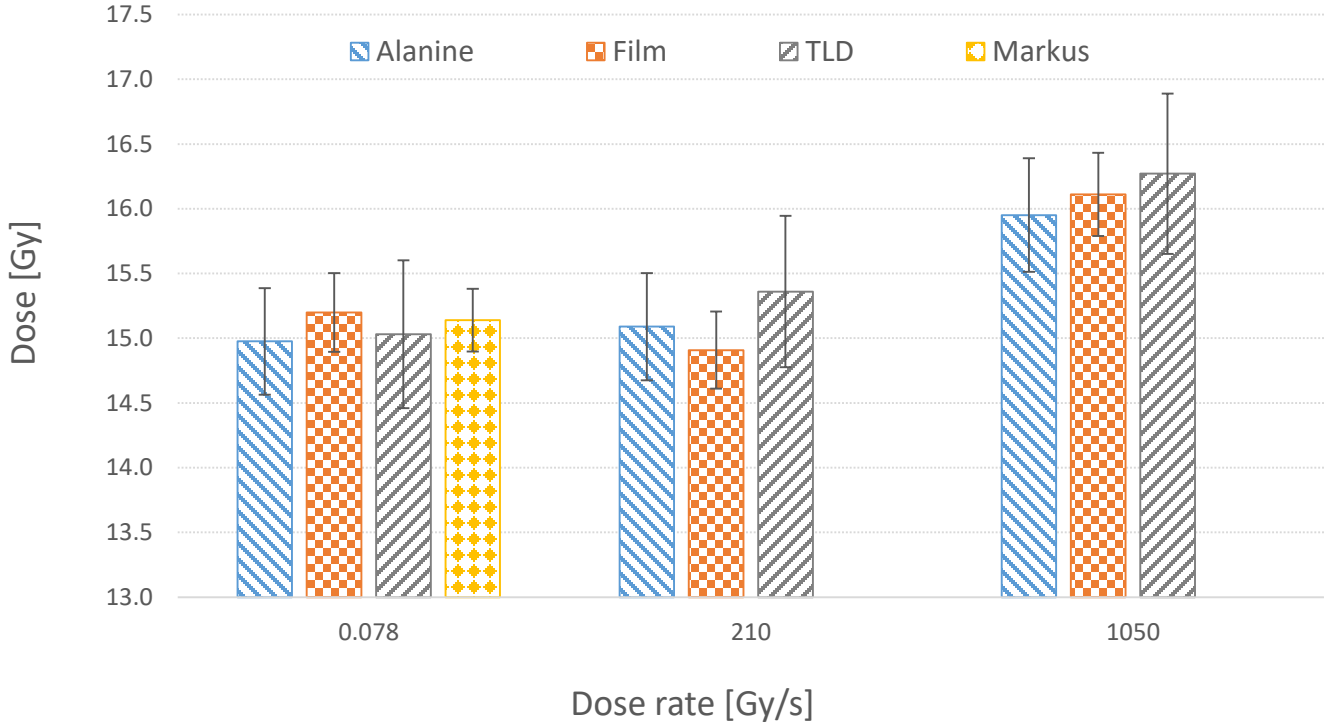
Fiv

- Ther
- Methyl viologen
- Alanine

Our strategy:

- **5 different detecting principles**
- **The dose rate dependency must be different**
- **Start with reference conditions (conventional LINAC) and extrapolate to Flash**

Redundancy of dosimetric measurements ▫▫▫▫⇨ traceability



Agreement within 3 % for FLASH and within 2 % for CONV

Maud Jaccard, Maria Teresa Durán, Kristoffer Petersson, Jean-François Germond, Philippe Liger, Marie-Catherine Vozenin, Jean Bourhis, François Bochud, Claude Bailat, High dose-per-pulse electron beam dosimetry: Commissioning of the Oriatron eRT6 prototype linear accelerator for preclinical use, Medical physics, doi: 10.1002/mp.12713

K. Petersson,M. Jaccard, JF Germond, T. Buchillier,F Bochud, J. Bourhis, MC Vozenin, C. Bailat, High dose-per-pulse electron beam dosimetry - A model to correct for the ion recombination in the Advanced Markus ionization chamber, Med Phys. 2017 Mar;44(3):1157-1167.

M. Jaccard, K. Petersson,T. Buchillier, JF Germond, MT Durán, MC Vozenin, J. Bourhis, FO Bochud, C. Bailat, High dose-per-pulse electron beam dosimetry: Usability and dose-rate independence of EBT3 Gafchromic films, Med Phys. 2017 Feb;44(2):725-735.

M. Jaccard, K. Petersson, T. Buchillier, C. Bailat, J.F. Germond, R. Moeckli, J. Bourhis, M.C. Vozenin, F. Bochud, Absolute dosimetry with EBT3 Gafchromic films in a pulsed electron beam at high dose-rate, Radiotherapy and Oncology, Volume 119, Supplement 1, April 2016, Page S690.

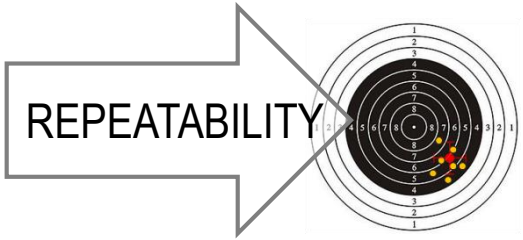
K. Petersson, M. Jaccard, T. Buchillier, C. Bailat, J. Germond, M. Vozenin, J. Bourhis, F. Bochud, The Advanced Markus ionization chamber is useable for measurements at ultra high dose rates, Radiotherapy and Oncology, Volume 119, Supplement 1, April 2016, Page S373.

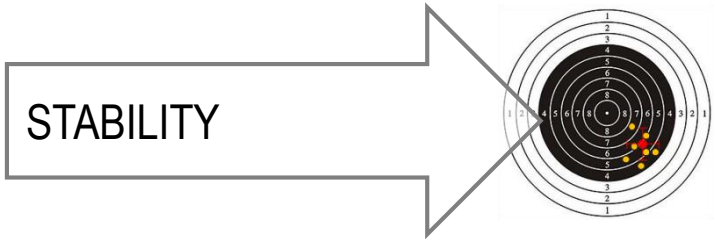
K. Petersson, M. Jaccard, M.C. Vozenin, P. Montay-Gruel, F. Trompier, T. Buchillier, J.F. Germond, F. Bochud, J. Bourhis, C. Bailat, Dosimetry of ultra high dose rate irradiation for studies on the biological effect induced in normal brain and GBM, Radiotherapy and Oncology, Volume 118, Supplement 1, 15–19 February 2016, Page S84

Our Goals for a safe use of FLASH-RT:

Ensure a **reliable** and **accurate** dose delivery

- Reliable
- Accurate
- Reproducible vs time



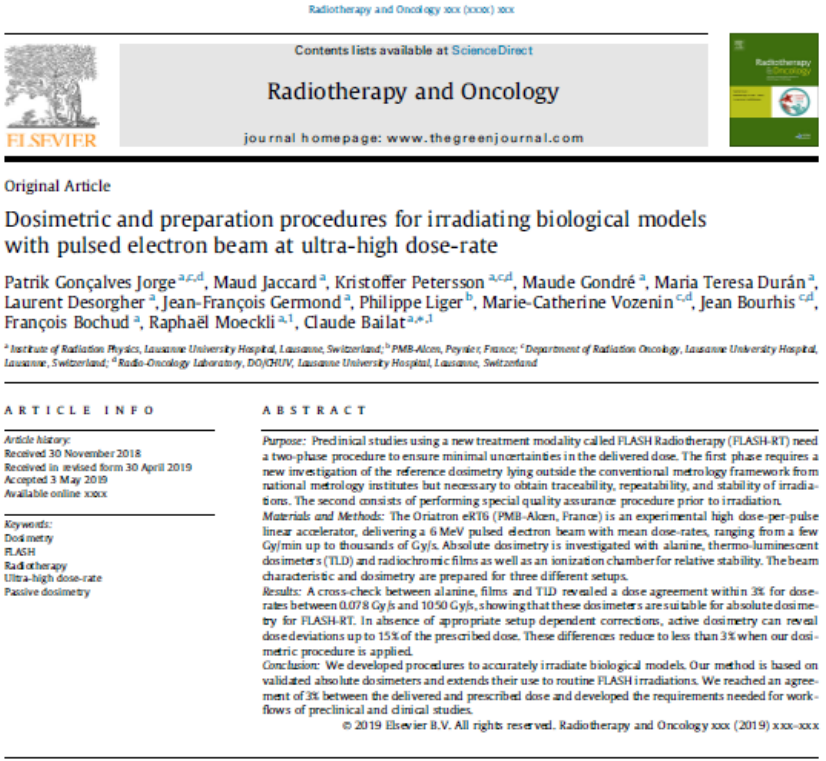


Development of procedures for pre-clinical FLASH-RT irradiation

Absolute dosimetry:
alanine, TLD, and radiochromic films.

Relative stability:
ionization chamber.

Routine irradiation:
beam characteristic and dosimetry are standardized for three different setups.



Radiotherapy and Oncology xxx (xxxx) xxx

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Original Article

Dosimetric and preparation procedures for irradiating biological models with pulsed electron beam at ultra-high dose-rate

Patrik Gonçalves Jorge[a,f,d], Maud Jaccard[a], Kristoffer Petersson[a,c,d], Maude Gondré[a], Maria Teresa Durán[a], Laurent Desorgher[a], Jean-François Germond[a], Philippe Liger[b], Marie-Catherine Vozenin[c,d], Jean Bourhis[c,d], François Bochud[a], Raphaël Moeckli[a,1], Claude Bailat[a,*,1]

[a] Institute of Radiation Physics, Lausanne University Hospital, Lausanne, Switzerland; [b] PMB-Alcen, Peynier, France; [c] Department of Radiation Oncology, Lausanne University Hospital, Lausanne, Switzerland; [d] Radio-Oncology Laboratory, DO/CHUV, Lausanne University Hospital, Lausanne, Switzerland

ARTICLE INFO

Article history:
Received 30 November 2018
Received in revised form 30 April 2019
Accepted 3 May 2019
Available online xxxx

Keywords:
Dosimetry
FLASH
Radiotherapy
Ultra-high dose-rate
Passive dosimetry

ABSTRACT

Purpose: Preclinical studies using a new treatment modality called FLASH Radiotherapy (FLASH-RT) need a two-phase procedure to ensure minimal uncertainties in the delivered dose. The first phase requires a new investigation of the reference dosimetry lying outside the conventional metrology framework from national metrology institutes but necessary to obtain traceability, repeatability, and stability of irradiations. The second consists of performing special quality assurance procedure prior to irradiation.

Materials and Methods: The Oriatron eRT6 (PMB-Alcen, France) is an experimental high dose-per-pulse linear accelerator, delivering a 6 MeV pulsed electron beam with mean dose-rates, ranging from a few Gy/min up to thousands of Gy/s. Absolute dosimetry is investigated with alanine, thermo-luminescent dosimeters (TLD) and radiochromic films as well as an ionization chamber for relative stability. The beam characteristic and dosimetry are prepared for three different setups.

Results: A cross-check between alanine, films and TLD revealed a dose agreement within 3% for dose-rates between 0.078 Gy/s and 1050 Gy/s, showing that these dosimeters are suitable for absolute dosimetry for FLASH-RT. In absence of appropriate setup dependent corrections, active dosimetry can reveal dose deviations up to 15% of the prescribed dose. These differences reduce to less than 3% when our dosimetric procedure is applied.

Conclusion: We developed procedures to accurately irradiate biological models. Our method is based on validated absolute dosimeters and extends their use to routine FLASH irradiations. We reached an agreement of 3% between the delivered and prescribed dose and developed the requirements needed for workflows of preclinical and clinical studies.

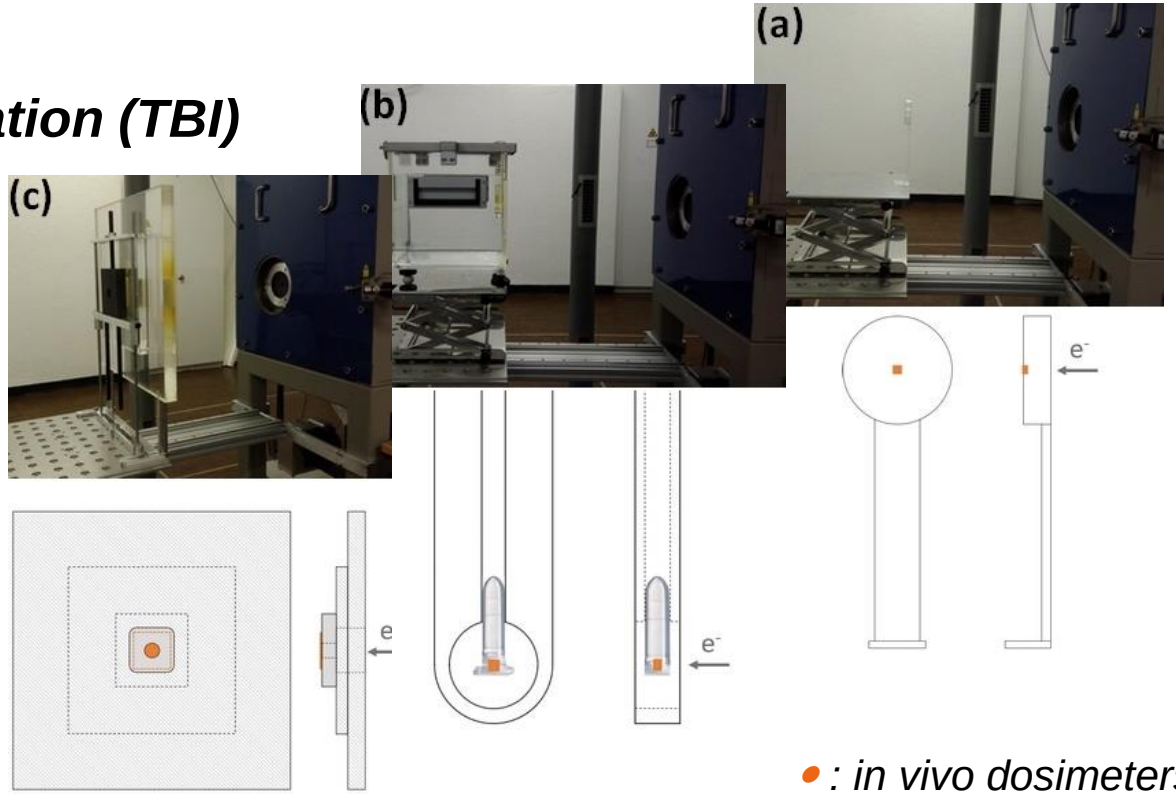
Development of procedures for pre-clinical FLASH-RT irradiation

For routine irradiation, beam characteristic and dosimetry are standardized for three different setups:

(a) mice Total Body Irradiation (TBI)

(b) zebrafish embryos

(c) mini-pig irradiation



● : *in vivo dosimeters*

Perspectives – issues –needs - hopes

- No microsecond monitoring: we are currently developing monitoring devices, in order to circumvent the passive dosimeters issues and improve irradiation flow.

- Active dosimeters are needed for clinical transfer: UHDpulse will provide calibration and test facilities → development of international protocols.

- The FLASH-RT multidimensional space is defined biologically (FLASH effect). We need to explore further the boundaries of this new territory.
  - We need irradiation facilities having very flexible beam characteristics.

Questions?