Development of Active Dosimeters for the ELIMAIA/ELIMED Beamline

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Abstract

High-power laser facilities generate ultra-short (sub-nanosecond), ultra-high dose-rate particle fields with instantaneous dose rates reaching $10^8 - 10^{10}$ Gy/s and complex mixed particle compositions including neutrons, photons, electrons, and protons. Accurate dosimetry under these conditions remains a major challenge due to detector saturation, recombination effects, limited temporal resolution, and strong electromagnetic pulse interference.

The EMPANADE (ElectroMagnetic Photon And Neutron Active DEtectors) project addresses these challenges through the development, benchmarking, and optimization of active radiation detectors for operation in extreme pulsed mixed fields. Commercially available systems, including BF_3 - and ^{3}He-based neutron detectors, organic scintillators, and ionization chambers, will be systematically evaluated across three complementary environments: the PW laser facility at ELI Beamlines, FLASH radiotherapy conditions at Lausanne University Hospital (CHUV), and the SwissFEL and neutron irradiation facilities at the Paul Scherrer Institute (PSI). Detector responses will be compared against passive dosimeters and supported by Monte Carlo simulations to quantify performance limits, linearity, energy response, and temporal behavior. Based on these results, firmware, readout electronics, and measurement protocols will be refined to improve resilience, dynamic range, and reliability in nanosecond-scale pulsed radiation fields.

The EMPANADE project is part of the newly formed international collaboration, SWISSELITE. This contribution presents the dosimetric challenges of ultra-high dose-rate pulsed radiation fields and the main characteristics of detectors that will be investigated. The EMPANADE project is part of the newly formed international collaboration, SWISSELITE. This contribution presents the dosimetric challenges of ultra-high dose-rate pulsed radiation fields and the main characteristics of detectors that will be investigated.

Dosimetric Challenges

1. Ultra-High Dose Rate: [1-3]

FLASH compared to conventional radiotherapy reduce damage to healthy tissues while maintaining tumor control by delivering radiation at ultra-high dose rates.

Table 1: Differences between FLASH and conventional radiotherapy [1-3]

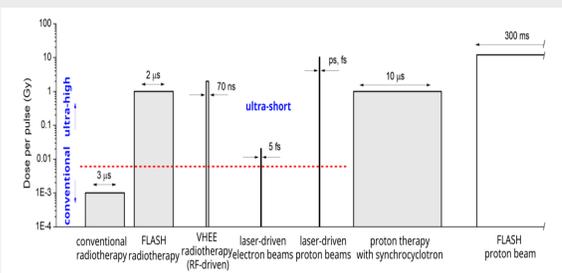| Parameter	FLASH	Conventional
Dose per Pulse	1 - 10 Gy	0.3 mGy
Pulse Width	1 - 2 μs	3 μs
Dose Rate During Pulse	10^6 Gy/s	10^2 Gy/s
Pulse Repetition Frequency	10 - 100 Hz	200 Hz
Mean Dose Rate	40 - 1000 Gy/s	0.05 Gy/s
Time for Dose Delivery	100 μs	4 min

Figure 1: Beams with ultra-high pulse dose rates. [3]

2. Laser-Driven Accelerators: [4-7]

Facts:
- Ultra-Short Pulses (< ns)
- Detector response time $\gg$ pulse duration
- Dose Rate: $10^8 - 10^{10}$ Gy/s
- Extremely high ionization density

Consequences:
- Charge recombination
- Detector saturation / non-linear response
- No resolution of pulse structure
- Uncertain dose measurements

3. Applications - ELIMAIA/ELIMED: [4-7]
- Laser-driven proton & ion beams
- Tunable energy & precise dosimetry
- Applications: radiobiology, preclinical studies, ion therapy, materials research

Table 2: Proton/Ion beam parameters at the ELIMAIA user beamline

Proton/Ion Accelerator	Available	Target
Laser Intensity	$5 \cdot 10^{21}$ W/cm^2	10^{22} W/cm^2
Laser Energy	~ 10 J	30 J
Laser pulse width	< 30 fs	< 30 fs
Repetition rate	3.3 Hz	10 Hz
Proton/Ion energy (max)	~ 40 MeV / ~ 15 MeV/u (C6+)	100 MeV / 60 MeV/u (C6+)
Proton/Ion flux (> 3 MeV)	$\sim 10^{10}$/sr / $\sim 10^9$/sr	$\sim 10^{11}$/sr

Figure 2: The ELIMAIA Ion Acceleration user beamline is at ELI Beamlines in Prague.

LB 6419

Consists of: [8-10]
- Plastic Scintillator
- Photomultiplier Tube
- ^{3}He Tube - REM Counter
- Polyethylene Moderator
- Cd absorbers
- Electronics - Box Power Supplies

Figure 3: LB 6419 from BERTHOLD: Neutron and Gamma dose rate monitor for Continuous and Pulsed Fields. [11]

Table 3: Neutrons Measurement Modes [8-10]

Neutrons		
Type of Radiation	Pulsed & Continuous	Burst Sequence
High Energy > 20 MeV	Scintillator: Pulse Height > MIP Recoil Protons	Scintillator: ^{12}C(n,p)^{12}B ^{3}He Counter: ^{12}C(n,x)^{9}Li
Low Energy < 20 MeV thermal	^{3}He Counter/ Scintillator	^{3}He Counter: TOF Scintillator: TOF capt. γ

Table 4: Photons Measurement Modes [8-10]

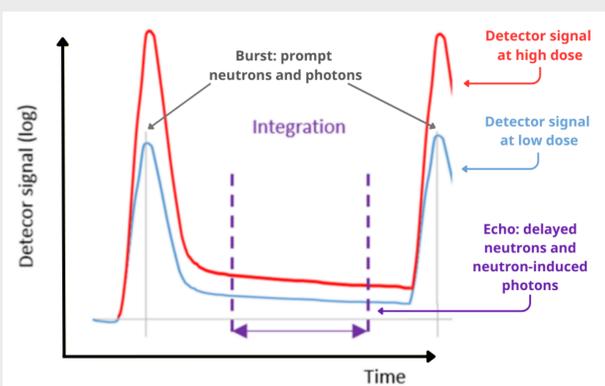| Photons		
Type of Radiation	Pulsed & Continuous	Burst Sequence
Bremsstrahlung > 2 MeV	Scintillator: Pulse Height < MIP	^{13}C(γ,p) ^{12}B
γ-radiation		-
Synchrotron Radiation		-

Figure 4: Detector signals of two pulses and the intermediate decay time of the reaction residuals. [11]

Acknowledgements

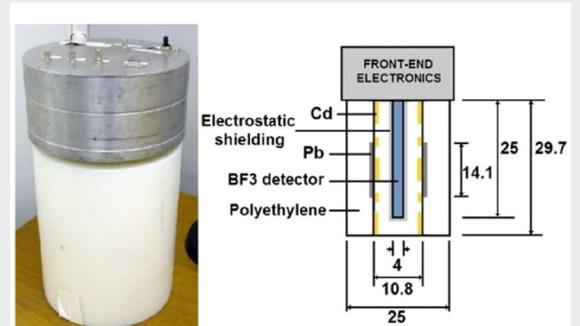## References

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LUPIN-II

Figure 5: LUPIN-II from ELSE NUCLEAR: Neutron REM meter in Pulsed Fields. A schematic drawing, all dimensions are in cm. [12]

Table 5: LUPIN-II Measurement Mode [13-15]

Neutrons			
Type of Radiation	Pulsed Neutron Fields	Reaction	Sensitivity
Thermal - 10 GeV	BF$_3$ version discriminates γ & n signals	^{10}B(n,a)^{7}Li	2 counts/nSv

$$\text{\# Neutrons} = \frac{\text{Integral Charge}}{\text{Mean Collected Charge}}$$

Mean Collected Charge = 600 fC for BF$_3$ [16-17]

LUPIN samples the current at a rate of 10 MHz and then reconstructs the outputs the time profile. [12]
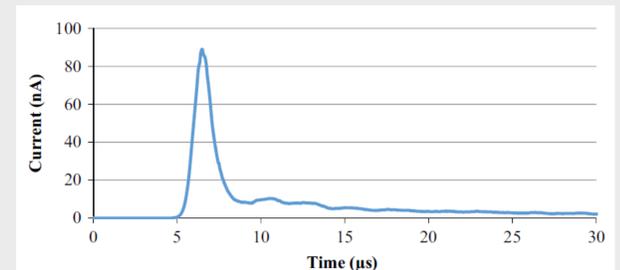

Figure 6: Single Neutron acquisition current signal. [12]

NAUSICAA

Consists of: [18-19]
- Ion Chamber: Gas (Ar/Xe)
- Power Supply and Signal Processing Electronics
- Acquisition and Control unit

Figure 7: NAUSICAA IC-T-PF from ELSE NUCLEAR: Gamma radiation monitor for Pulsed Fields. [19]

Table 6: NAUSICAA Measurement Features [18-19]

Photons			
Energy Range	Pulsed Fields	Measurement Range	Accuracy
30 keV - 10 MeV	7 decades electrometer	10nSv/h - 100mSv/h	±5%