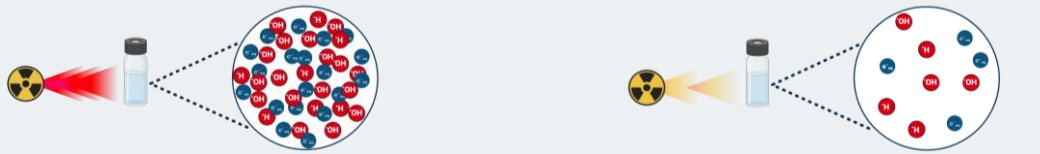
ESR Spin Trapping and Spin Probing for the Investigation of Radical-Radical-Recombination in Flash and Conventional Electron Radiotherapy

Johanna Pehlivan[1], Elke Beyreuther[2,3], Felix Horst[2,4], Dieter Leichtle[1], Michael J. Nasse[5], Jörg Pawelke[2,4], Oliver Jäkel[6,7], Bernhard Holzapfel[8]

[1]Karlsruhe Institute of Technology, Institute for Neutron Physics and Reactor Technology, Germany; [2]OncoRay – National Center for Radiation Research in Oncology, Faculty of Medicine and University Hospital Carl Gustav Carus, Dresden University of Technology; Helmholtz-Zentrum Dresden-Rossendorf, Germany; [3]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Radiation Physics, Dresden, Germany; [4]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Radiooncology-OncoRay, Dresden, Germany; [5]Karlsruhe Institute of Technology, Institute for Beam Physics and Technology, Germany [6]German Cancer Research Center, Division of Medical Physics in Radiation Oncology, Germany; [7]Heidelberg Ion Beam Therapy Center at Heidelberg University Hospital, Germany; [8]Karlsruhe Institute of Technology, Institute for Technical Physics, Germany

Background & Motivation

- Radical-radical recombination hypothesis
- Extremely high short-term radical concentrations → more recombination
- Altered radical processes → less oxidative stress in normal tissue



Ultra-high dose rate (UHDR)

$e^-_{aq} + e^-_{aq} + 2\,H_2O \rightarrow H_2 + 2OH^-$

$H\bullet + H\bullet \rightarrow H_2$

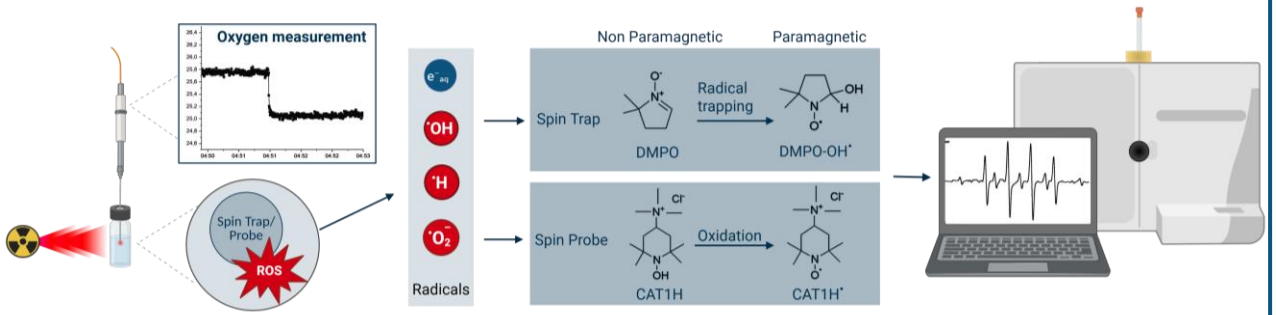
Conventional dose rate (CDR)

$e^-_{aq} + O_2 \rightarrow O_2^-$

$H\bullet + O_2 \rightarrow HO_2\bullet$

Experimental Conditions

- **Irradiation:** 30 MeV electron beam at ELBE, HZDR
- **Mean Dose Rates:** CDR 0.1 Gy/s, UHDR up to 10^5 Gy/s
- **Radical Detection:** Electron Spin Resonance (ESR)
  - Detection of trapped or oxidized paramagnetic products
  - Spin traps (DMPO, BMPO, DEPMPO) and spin probes (CAT1H, CMH, TMTH)



Results

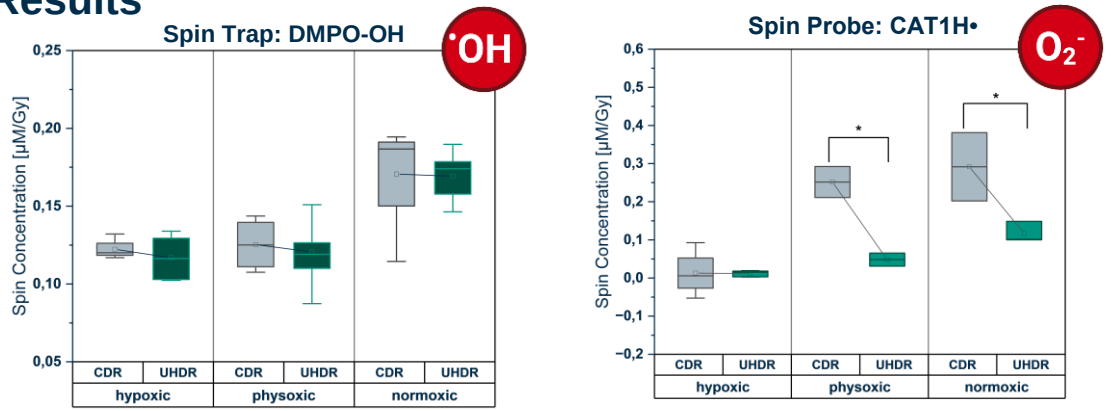


Figure 1: Dose-normalised DMPO (OH•) and CAT1H (O_2•–) signals under hypoxic, physioxic and normoxic conditions at CDR and UHDR.

- Reduced superoxide signal for spin probes at UHDR
- Initial oxygen concentration affects both spin trap and spin probe signals
- No dose-rate effect for spin traps, likely driven by adduct stability and kinetics

Conclusion

- Spin traps and spin probes offer complementary, not interchangeable insights into radical chemistry
- Data support radical-radical recombination as a contributor to the Flash effect
- Water isolates the chemistry but misses key biological interactions
- Next steps require moving to more realistic systems

johanna.pehlivan@kit.edu

Pehlivan et al. (submitted to Physics in Medicine and Biology); Illustrations created in https://BioRender.com