

Physics

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Development of a 3D FLASH Carbon-Ion Irradiation System for Animal Studies

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Background / Aims:

We propose the “Carbon Knife” to target millimeter-scale lesions & nonneoplastic targets. This microbeam concept integrates 3D scanning irradiation planning, ultra-high dose-rate (UHDR) delivery, and 3D range modulator (3D-RM) for small-animal research.

Subjects and Methods:

1. CT-Stopping Power Ratio (SPR) Calibration

- 30 mm phantom for animal CT.
- SPRs benchmarked for olive oil, lard, milk, pork.

2. 3D Scanning Irradiation Planning

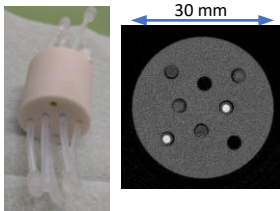
- In-house software developed. *

3. UHDR Delivery

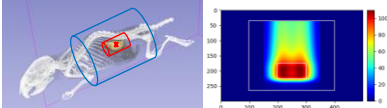
- RF-knockout and IF-converter adjusted for both conventional & UHDR beam modes.
- Dose monitor linearity verified up to 300 Gy/s.
- Advanced Markus chamber stability verified.

4. 3D Range Modulator (3D-RM)

- 3D-printed ridge filters and range compensators shaped SOBPs for arbitrary lateral positions.



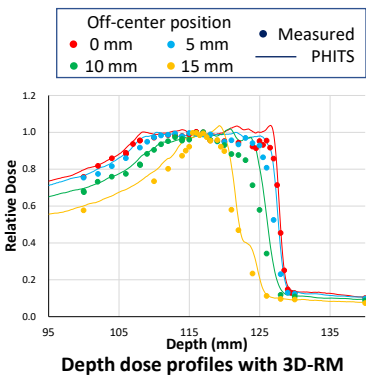
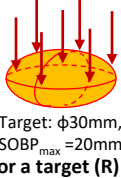
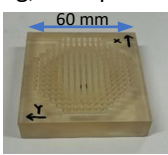
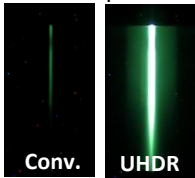
SPR calibration phantom for animal CT



Irradiation planning*

Results:

- **SPR accuracy:** CT-based SPRs agreed within 5% of measured values.
- **Planning accuracy:** Measured doses matched plans within a few %. *
- **UHDR performance:** Reached **100 Gy/s** (10 Gy, 20×20 mm², 290 MeV/u plateau) and **200 Gy/s** (30 Gy, 10×10 mm², 10 mm SOBP). Dose monitor linearity maintained.
- **3D-RM fidelity:** SOBP widths slightly blurred by neighboring ridge height differences and multiple scattering; dose profiles matched PHITS.



Typical UHDR irradiation conditions

290 MeV/u	Field(mm)	LET(keV/μm)	Dose(Gy)	Dose Rate(Gy/s)
Mono	□14	13	30	222
	□20	13	10	112
	□10	70	18	287
SOBP 10mm	□10	SOBP Center 80	34	229
	□20		24	91
	□30		11	43

Summary / Outlook:

Key components are currently being tested within a 3D carbon-ion irradiation platform for small-animal studies, aiming to enable high-precision radiobiology experiments.

*For details, see a poster **ABS-0013** (by Inagaki et al).

This study was conducted as part of a research project on heavy ions at GHMC.