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Determination of Dose Distributions in High-Dose-Rate Co-60 Brachytherapy for Cervical Cancer Using MCNP Simulations and OSL Dosimetry

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Introduction

High-dose-rate (HDR) brachytherapy is an essential method for treating cervical cancer, as it allows the delivery of high radiation doses to small target areas, creating sharp dose gradients while sparing surrounding healthy tissue [1].At the National Institute of Neoplastic Diseases (INEN), this treatment is carried out using the SagiNova® afterloading system, which utilizes Co-60 and Ir-192 sources, with planning conducted in SagiPlan® following the TG-43 formalism. However, TG-43 assumes a homogeneous water medium, which does not fully reflect patient anatomy, including heterogeneities like bone, air cavities, and tissues of varying densities. These assumptions can cause differences between the planned and actual delivered dose, potentially impacting treatment accuracy and safety. To address this, Monte Carlo simulations using MCNP combined with OSL dosimetry provide a more realistic assessment of dose distributions.

Contributions

- Perform dosimetric characterization of the Co-60 source in MCNP5 by assessing its anisotropy, dose rate function, and air kerma.
- Use Monte Carlo simulations to determine the dose distribution at positions corresponding to the clinical placement of OSL NanoDot dosimeters.
- Develop and construct a three-dimensional cylindrical phantom to enable realistic clinical evaluation studies for Co-60 HDR brachytherapy.
- Create a phantom treatment plan in SagiPlan that incorporates OSL dosimeters to closely replicate clinical HDR irradiation conditions.
- Validate the dose distribution experimentally with OSL dosimetry by comparing MCNP simulation results to dose calculations from the clinical TPS.

1 Experiments & Methodology

The HDR Co-60 source (model Co0.A86) was represented in MCNP5 as a cylindrical active core enclosed in a stainless-steel capsule. Photon transport was simulated with detailed geometric modeling to enable validation. Air-kerma strength at a distance of 1 m was obtained using the F6 tally. The radial dose function and anisotropy were evaluated from calculations in the transverse plane and with point detectors in a spherical water phantom, in accordance with TG-43 recommendations, and the results were compared to reference data.

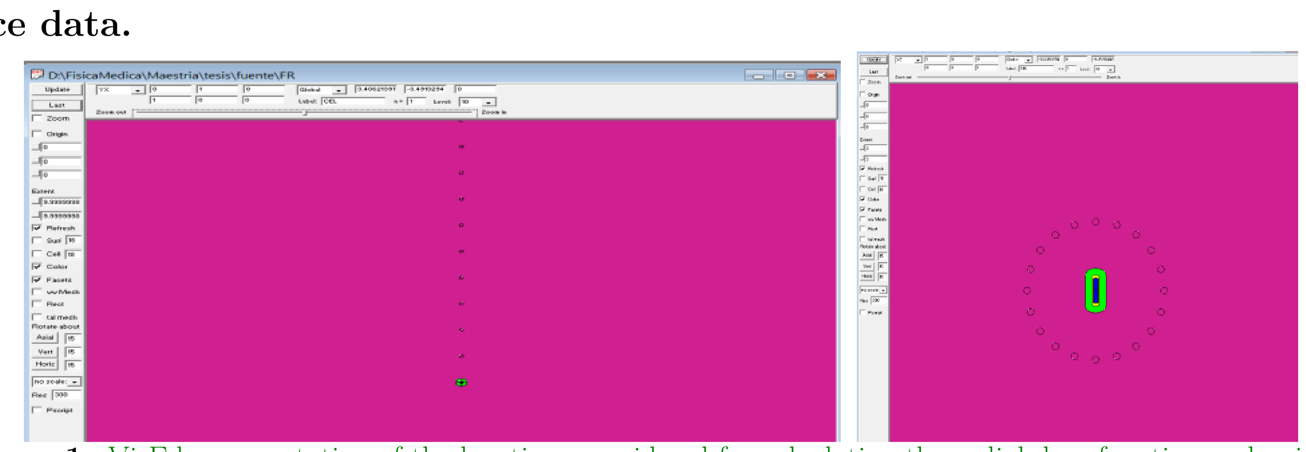

Figure 1: VisEd representation of the locations considered for calculating the radial dose function and anisotropy.

Absorbed dose distributions were calculated in units of Gy using the F6 tally and appropriate normalization factors, accounting for source activity and irradiation time. Simulated NanoDot dosimeters were positioned at radial distances of 1, 2, 3, and 4 cm from the source center. Both sagittal and transverse configurations were considered to reproduce the experimental measurement geometry.

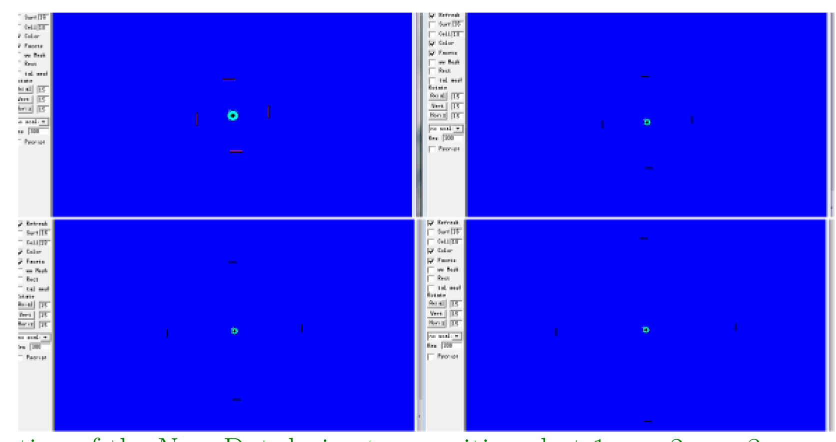

Figure 2: VisEd representation of the NanoDot dosimeters positioned at 1 cm, 2 cm, 3 cm, and 4 cm from the Co-60 source.

A 3D-printed cylindrical phantom (12 × 13 cm) with a central channel and holders for NanoDots was scanned using Discovery™ CT. Images were imported to SagiPlan® to prescribe 2 Gy at 1 cm from the source and define dose calculation points. NanoDot dosimeters were irradiated with SagiNova® HDR Co-60 at 1–4 cm distances. Readings were obtained using a MicroStar® reader and corrected for Co-60 energy. Measured doses were compared with MCNP5 simulations and SagiPlan® results.

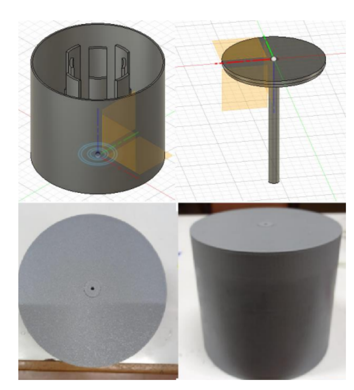

Figure 3: Design and 3D printing of the cylindrical phantom

2 Results || Conclusions

MCNP5 simulations estimated absorbed doses at 1–4 cm from the Co-60 source in a cylindrical phantom. Four NanoDot™ dosimeters per distance were used. Relative errors ranged 1–4% TPS comparisons showed differences below 3%. Experimental measurements matched simulations within 5%, confirming dose distribution accuracy and the reliability of both simulation and planning approaches.

d(cm)	MCNP5 (Tally F6) Dosis (Gy)	MCNP5 (Tally F6) Error Relativo	TPS Dosis (Gy)	nanoDot Dosis (Gy)	MCNP5 Vs TPS	MCNP Vs OSL	TPS Vs OSL
1	2,24	0,01	2,31	2,35	2,9%	4,7%	1,9%
	2,27	0,01	2,33	2,39	2,7%	5,0%	2,4%
	2,29	0,01	2,35	2,39	2,6%	4,2%	1,6%
	2,26	0,01	2,32	2,38	2,7%	5,0%	2,4%
2	0,58	0,02	0,57	0,56	2,8%	5,2%	2,3%
	0,58	0,02	0,59	0,61	2,7%	5,0%	2,3%
	0,57	0,02	0,55	0,54	2,9%	4,9%	1,9%
	0,58	0,02	0,56	0,55	2,9%	5,1%	2,2%
3	0,25	0,03	0,26	0,27	2,3%	5,2%	3,0%
	0,25	0,03	0,26	0,26	2,7%	5,0%	2,3%
	0,24	0,03	0,25	0,26	2,4%	5,1%	2,7%
	0,26	0,03	0,26	0,28	2,6%	5,1%	2,6%
4	0,14	0,04	0,14	0,14	2,9%	5,1%	2,2%
	0,14	0,04	0,14	0,15	2,8%	4,8%	2,1%
	0,14	0,04	0,14	0,15	2,7%	5,3%	2,6%
	0,14	0,04	0,15	0,14	2,1%	5,1%	2,9%

Table 1: Table caption

MCNP5 simulations accurately characterized the Co-60 HDR source, providing radial dose and anisotropy data. NanoDot™ measurements validated simulations, showing deviations within 5%. TPS planning agreed within 3%. Experimental integration with SagiPlan® demonstrates feasible dose verification, supporting reliable HDR brachytherapy dose delivery and planning validation

References

[1] Bozkurt A. Kemikler G. Acun Bucht, H. Dosimetric accuracy of an hdr brachytherapy treatment planning system for different irradiation lengths with monte carlo simulation. *Applied Radiation and Isotopes*, pages 102–108, 2019.