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Article

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Abstract

Brachytherapy relies on accurate spatial dose delivery and therefore requires precise modeling of radioactive sources within complex applicator geometries. In this work, we present a detailed Monte Carlo–based dosimetric analysis of a spiral catheter configuration using the Geant4 toolkit. Analytical energy-balance estimates, empirical absorbed-dose values, and full Monte Carlo energy-deposition calculations were integrated and compared as three independent approaches to validate dose estimation. The radionuclide ^{166}Ho was modeled by explicitly simulating its β-emission energy spectrum and physical half-life, and dose distributions were quantified using both voxelized meshes and detector-specific scoring geometries. The results demonstrate agreement within 5–7% between empirical absorbed-dose estimates and Monte Carlo calculations, supporting the accuracy of the simulation framework and the feasibility of the spiral catheter design for brachytherapy applications. High localized dose deposition was observed in the immediate vicinity of the catheter, with a delivered dose of approximately 43.0 Gy/GBq in a 0.001 g voxel, indicative of a potent and spatially confined therapeutic dose achievable in clinical practice.

Keywords:
Monte Carlo dosimetry; beta-emitting brachytherapy; spiral catheter; holmium-166; Geant4; interventional oncology

1. Introduction

Brachytherapy, defined as the placement of radioactive sources in direct contact with or in close proximity to target tissues, requires highly accurate dose calculation to ensure effective tumor control while maintaining patient safety. Conventional treatment planning systems often rely on analytical or semi-empirical methods, such as those recommended by the AAPM TG-43 protocol [1], which assume simplified source geometries, homogeneous water-equivalent media, and radial dose symmetry. While this formalism is well established for photon brachytherapy, no TG-43–equivalent consensus standard exists for beta-emitting brachytherapy sources [2].

In this work, we introduce and dosimetrically characterize the SISLOT spiral catheter, a novel applicator concept that, to our knowledge, has not been previously reported in the context of beta-emitting brachytherapy.

The SISLOT catheter is an innovative prototype spiral applicator engineered for localized brachytherapy delivery. Its unique helical geometry allows the flexible positioning of radioactive material along a controlled spiral path (represented in Figure 1), providing the potential to achieve uniform and conformal dose coverage of irregularly shaped target regions. By incorporating the β-emitting radionuclide holmium-166 (^{166}Ho), the device can be tailored to specific clinical requirements for highly localized therapy, owing to its favorable half-life, short beta range, and intrinsic imaging capability. To our knowledge, no clinical or preclinical applications of ^{166}Ho have been reported in the context of catheter-based brachytherapy, although the radionuclide is widely used for intratumoral and intra-arterial therapies via microsphere delivery [3].

This spiral catheter's geometry, the variations in curvature, the radial position of the active radioactive layer, and the presence of polymer encapsulation contribute to complex dose distributions that cannot be accurately described by analytical formalisms. Consequently, advanced modeling techniques are necessary to fully characterize the dose distribution and optimize the catheter design for clinical use.

This study systematically investigates different loading configurations of the SISLOT catheter, aiming to identify arrangements that deliver a homogeneous and therapeutically relevant dose in the immediate proximity of the catheter, while minimizing radiation exposure to surrounding healthy tissues. The use of Monte Carlo modeling with the Geant4 toolkit [4-6]

offers distinct advantages in this context. It allows explicit and detailed representation of each spiral turn, including the multilayer material composition of the catheter. Additionally, it provides full three-dimensional dose scoring capabilities in both water-equivalent phantoms and idealized tissue environments, enabling accurate modeling of β^- particle scattering, secondary photon transport, and self-absorption phenomena within catheter materials.

The primary objectives of this work are to develop a comprehensive Monte Carlo model of the SISLOT spiral catheter loaded with ^{166}Ho, including detailed geometric and material specifications, to evaluate dose distributions for multiple catheter loading configurations with the goal of optimizing dose uniformity and minimizing healthy tissue exposure, and to validate the Monte Carlo model through comparison with analytical and empirical dose calculations to ensure its reliability for future clinical application.

2. Results

2.1 Catheter and Radioisotope Characteristics

The SISLOT spiral catheter prototype examined in this study features a cylindrical length of 10 mm, with multiple concentric radii defining its internal and external architecture. The radioactive material is confined within an annular region extending from 1.5 mm to 1.9 mm in radius, which is further encapsulated by polymer layers reaching an outer radius of 2.5 mm. The simulated SISLOT geometry is shown in Figure 2. The activity incorporated into the spiral catheter was computed based on an initial beam-on of 1×10^7 nuclei, corresponding to an initial activity of 72 Bq.

2.2 Dose Calculation: Expected, Empirical, and Monte Carlo

Dose deposition was assessed through three distinct but complementary methodologies. The theoretical dose expectation, derived from the mean β-energy per decay within the scoring mesh volume, amounted to an energy deposition of 1.0656×10^{-6} joules, translating to an expected dose of 2.13×10^{-5} gray (Gy). This value was normalized to a reference dose of 14.85 Gy per GBq per kilogram. Empirical dose calculations, utilizing established reference formulae, produced a marginally higher energy deposition estimate of 1.14×10^{-6} joules and an associated dose of 2.28×10^{-5} Gy, which corresponds to a normalized reference dose of 15.87 Gy per GBq per kilogram. The Monte Carlo simulation, incorporating detailed modeling of the spiral catheter geometry, β-particle scattering, bremsstrahlung generation, and self-

absorption effects, yielded an energy deposition of 1.12×10^{-6} joules and a dose of 2.24×10^{-5} Gy. The corresponding normalized reference dose was 15.62 Gy per GBq per kilogram.

Comparison among these three approaches reveals a close concordance. The ratio of empirical to expected dose stands at 1.07, Monte Carlo to expected at 1.05, and Monte Carlo to empirical at 0.98. These findings affirm the internal consistency and validate the accuracy of the Monte Carlo simulation model in relation to classical dose estimation methods.

2.3 Local Dose Distribution in Dosimeter Voxels

The Monte Carlo dose scoring at the voxel scale demonstrated marked spatial heterogeneity attributable to the spiral geometry of the catheter. For the smaller dosimeter voxel, with a mass of 0.001 grams located at the origin, the deposited energy was measured at 3.09×10^{-12} joules, corresponding to a dose of 3.09×10^{-6} Gy. When normalized per GBq of activity, this implies a substantially high localized dose rate of approximately 43.0 Gy per GBq, indicative of a potent therapeutic dose concentration in the immediate vicinity of the radioactive source.

Conversely, the larger voxel, with a mass of 0.125 grams situated at the same coordinates, exhibited an energy deposition of 4.92×10^{-9} joules and a dose of 3.93×10^{-5} Gy. When normalized, this equates to a dose of 548.1 Gy per GBq. The higher absorbed dose per GBq observed in larger voxels reflects partial inclusion of regions closer to the radioactive layer and spatial averaging over heterogeneous dose distributions, rather than a true increase in local dose.

Further Monte Carlo calculations using a mesh-based approach confirmed the presence of spatial dose gradients. The measured dose values in small voxels reached 4.42×10^{-6} Gy (61.55 Gy per GBq), while larger voxels recorded doses of 1.53×10^{-5} Gy (213.22 Gy per GBq). These results highlight the complex interaction among catheter geometry, radionuclide distribution, and local dose deposition patterns.

Dose distributions in the plane perpendicular to the central axis of the two-turn spiral are shown in Figure 3, while the corresponding dose profile along a line crossing the spiral-to-spiral axis is shown in Figure 4.

4. Discussion

This study provides a comprehensive Monte Carlo modeling approach to characterize the dosimetric behavior of the SISLOT spiral catheter loaded with ^{166}Ho. The spiral geometry of the catheter presents unique dosimetric challenges that required augmentation by detailed three-dimensional Monte Carlo simulations to capture the complexities introduced by the spiral configuration itself and by the multilayered catheter materials.

The close agreement (within 7%) between the analytical energy-balance estimate, the empirical absorbed-dose estimate, and the Monte Carlo result in a simple homogeneous geometry supports the internal consistency of the model and falls within clinically acceptable uncertainty for beta-emitting therapies [10]. This concordance also supports the reliability of the nuclear decay data and physics models implemented in Geant4, particularly regarding β-particle transport and secondary photon generation at the low energies pertinent to ^{166}Ho therapy [9,10]. The minor differences between empirical and simulated doses likely reflect the refined treatment of scattering, bremsstrahlung production, and self-absorption in the Monte Carlo approach, which are oversimplified or neglected in analytical calculations.

The detailed Monte Carlo simulation in the SISLOT environment provided absolute dose measurement and dose distribution using scoring at the voxel level further revealing pronounced spatial heterogeneity within the immediate vicinity of the catheter. The observed elevated dose in small voxels adjacent to the radioactive layer highlight the steep dose gradients characteristic of β-emitting sources with short electron ranges in tissue [11]. This behavior aligns with micro-dosimetric investigations indicating that the highest dose is concentrated in a small volume surrounding the source, with an abrupt dose falloff beyond a few millimeters due to limited β-particle penetration [12]. The disparity in dose estimates between small and larger voxels underscores the critical influence of voxel size and measurement resolution on dose reporting. In clinical terms, this implies that dose averaging over larger volumes may underestimate peak dose concentrations that are therapeutically relevant for tumor control but could also increase risk to adjacent normal tissue if not carefully managed.

The spiral geometry of the SISLOT catheter offers the potential for improved dose conformity to irregularly shaped target volumes. By modulating catheter geometry, it may be possible to achieve more uniform dose distributions along the spiral path while simultaneously reducing

unwanted radiation exposure to surrounding healthy tissues, thereby enhancing therapeutic efficacy and safety.

The inclusion of ^{166}Ho as the radionuclide source confers additional clinical advantages. Its physical half-life of approximately 27 hours balances treatment duration with radioprotection considerations, and its β-particle energy spectrum ensures localized dose delivery within a confined radius, minimizing off-target irradiation. The concurrent emission of low-energy γ photons facilitates imaging-based dosimetry verification using SPECT, supporting theragnostic applications where treatment and monitoring are integrated [13]. Such dual functionality aligns with current trends in personalized radionuclide therapy, where precise dosimetry and treatment adaptation are essential to optimize outcomes [14].

From a methodological standpoint, the use of a detailed Geant4 Monte Carlo model incorporating the full three-dimensional spiral geometry and multilayer catheter structure represents a significant advancement over conventional dosimetry protocols. It enables a nuanced understanding of dose deposition patterns that are critical for device design optimization and clinical implementation. However, this study also acknowledges certain limitations. The use of a homogeneous water-equivalent phantom neglects anatomical heterogeneities such as tissue density variations and organ boundaries, which could affect dose distributions in vivo. Future work should incorporate patient-specific imaging data and heterogeneous tissue compositions to further refine dose calculations. S ISLOT is conceived to be placed in direct contact with tumor tissue, which can be reasonably approximated as water-equivalent. From the point of view of the Monte Carlo simulation we acknowledge that a more detailed simulation could include a dedicated analysis of the dosimetric contribution of internal bremsstrahlung as described in Amato et al. for ^{90}Y [15] and ^{32}P [16]. We would then expect that our local dose would be higher which poses an advantage in our settings in which we have no limitation in higher dose since the catheter is placed directly on the tumor and we do not expect dose to the surrounding healthy tissues.

From the micro-dosimeter studies conducted, the dose distribution is highly heterogeneous, with very high dose concentrations localized near the center of the spiral catheter and a sharp decrease in dose with increasing distance. Specifically, small-volume dosimeters positioned close to the source recorded doses on the order of 43 Gy per GBq, whereas larger volume dosimeters at the same spatial location averaged much lower doses due to spatial averaging

effects. This confirms the expectation of a high dose delivered to a small volume immediately adjacent to the catheter, with a rapid dose fall-off radially, which is critical for effective tumor targeting while sparing healthy tissues.

Achieving these objectives holds significant clinical importance. Localized brachytherapy using ^{166}Ho-loaded spiral devices offers potential advantages in treating tumors situated in anatomically challenging locations where conventional sources may be suboptimal. The ability to tailor dose distribution along a spiral catheter path may improve treatment efficacy and reduce side effects, representing a meaningful advancement in brachytherapy technology by enabling dose delivery in geometries not achievable with conventional linear or seed-based applicators. Moreover, even if this paper concentrates on ^{166}Ho, therapeutic dose distribution could be achieved easily also with other β-emitters with longer electron range, such as ^{90}Y.

In conclusion, this investigation underscores the necessity of advanced three-dimensional dosimetric modeling for novel brachytherapy applicators such as the SISLOT spiral catheter. The promising dosimetric characteristics of the ^{166}Ho-loaded spiral design, demonstrated here through Monte Carlo simulations, suggest potential clinical benefits in delivering conformal and controlled radiation doses to complex tumor geometries. This work lays a foundation for further optimization and translation of spiral catheter-based brachytherapy into clinical practice, contributing to the evolving landscape of personalized and precision radiotherapy.

4. Methods

4.1 Monte Carlo Simulation Framework

All particle transport and energy deposition calculations were performed using the Geant4 toolkit (version 11.0.4), a widely adopted open-source C++ Monte Carlo simulation platform developed at CERN [4-6]. Geant4 supports comprehensive modeling of particle–matter interactions across a broad range of energies; in this work, low-energy electromagnetic models were employed to accurately simulate β^- transport and secondary photon production [7]. Its modular design allows the selection of physics models customized for specific particle types, energy ranges, and application requirements.

For this study, the simulation was configured to utilize Geant4's low-energy electromagnetic physics models [7]. This configuration facilitates precise modeling of β^- electron transport and secondary photon production down to energies of a few kilo-electronvolts, which is crucial for accurately representing the physical processes involved in brachytherapy with ^{166}Ho. ^{166}Ho predominantly emits β^- particles with a maximum energy of approximately 1.85 MeV but a significant fraction of which lies below 500 keV. The short spatial range of these electrons in tissue, on the order of a few millimeters, necessitates detailed simulation of scattering, energy loss, and bremsstrahlung production to reliably predict the local dose distribution.

Radioactive decay was simulated through the G4RadioactiveDecay module, which accesses Evaluated Nuclear Structure Data Files (ENSDF) [8] to reproduce the β^- and γ energy spectra, branching ratios, and half-life of ^{166}Ho accurately. This approach ensures faithful representation of both primary β^- emissions and secondary photon emissions, which is critical for precise dosimetry calculations in proximity to the SISLOT catheter.

4.2 Clinical Device: The SISLOT Spiral Catheter

The SISLOT catheter is a prototype brachytherapy applicator designed to deliver a spatially modulated or homogeneous radiation dose along an extended intraluminal pathway. Its defining characteristic is a spiral (helical) configuration, which distinguishes it from conventional linear or point-source applicators. By winding a hollow cylindrical tube into a controlled helix, the device closely conforms to internal tumor contours, potentially improving dose conformity while maintaining mechanical stability and reproducibility.

The active segment of the catheter consists of a thin cylindrical shell impregnated with therapeutic ^{166}Ho. This radioactive layer is positioned concentrically around the spiral axis at a radial distance ranging from 1.5 to 1.9 mm, ensuring β^- particle emissions deposit energy primarily within a few millimeters of the catheter surface. Internally, a non-radioactive polymeric cylindrical tube with internal and external diameters of 0.1 and 1.5 mm, respectively, provides flexibility and mechanical integrity necessary to maintain the spiral geometry. The entire assembly is encapsulated within a biocompatible sheath of internal and external radius of 2.4 mm and 2.5 mm, respectively, which secures the radionuclide while providing a smooth interface with surrounding tissues, minimizing mechanical irritation and avoiding contamination risks.

The geometry of the SISLOT catheter can be adapted to different tumor shapes and sizes. For this study, the reference geometric parameters include an initial turn diameter of 10 mm, a pitch of 10 mm between turns, and an expansion to a final turn diameter of 50 mm, resulting in two complete turns and an active length of approximately 189.8 mm. Given the limited β^- range of ^{166}Ho in tissue, precise tuning of geometric parameters is vital to achieve homogeneous target coverage.

4.3 Radionuclide Properties

^{166}Ho was selected due to its favorable physical and radiological characteristics suited for localized brachytherapy. Its half-life of approximately 26.83 hours strikes an appropriate balance between therapeutic efficacy and patient safety by limiting prolonged radiation exposure.

^{166}Ho decays predominantly via β^- emission, with a mean β-particle energy of approximately 0.666 MeV. The continuous slowing down approximation range of β particles in water or soft tissue at this energy is roughly 2 to 4 millimeters, effectively confining the therapeutic dose near the source and sparing adjacent healthy tissue. The dose heterogeneity introduced by electron scattering within tissue is explicitly modeled in Monte Carlo simulations to replicate realistic dose distributions.

Additionally, ^{166}Ho emits low-intensity γ photons at approximately 80.6 keV, which facilitates imaging-based dosimetry verification via single-photon emission computed tomography (SPECT), thus enhancing treatment planning and catheter visualization.

4.4 Dose Evaluation and Monte Carlo Validation

The Monte Carlo model was validated through a series of energy- and dose-deposition calculations within a cubic water phantom (edge length 10 cm; mass 1 kg). Dose estimates derived from Monte Carlo simulations were compared against two independent approaches.

The analytical dose estimation involved calculating the total deposited energy E_{dep} as the product of the total number of disintegrations, N, and the mean energy released per emitted particle, E, expressed in joules. Dose values were normalized to a reference activity A_{ref} = 1 GBq, with dose D scaled accordingly based on the initial source activity A_0.

Empirical mean absorbed dose values from the literature, corresponding to a uniform ^{166}Ho distribution in a 1 kg of water and complete local energy absorption, yield approximately 15.87 Gy/GBq [9].

The Monte Carlo dose calculation was obtained by summing the energy depositions $E_{dep,i}$ over all the scoring voxels and normalizing by the total mass of the scoring volume, ensuring consistency with reference dose definitions. Comparison among analytical, empirical, and Monte Carlo dose values served to validate the accuracy and reliability of the Monte Carlo model for SISLOT catheter dosimetry.

4.5 Simulation Setup and Scoring

Simulations explicitly modeled the detailed SISLOT catheter geometry, including the radioactive coating, polymeric core, and biocompatible sheath. Spiral helix parameters such as diameter, pitch, and length were parameterized to replicate the prototype applicator with high fidelity.

The catheter was immersed in a water-equivalent phantom with density d =1 g/cm^3 to simulate soft tissue interactions. Although anatomical heterogeneity was not included, this simplification enables direct comparison with standard dosimetric data.

Dose scoring was performed using two complementary methods. First, the volume surrounding the catheter was discretized into a cubic voxel mesh with voxel dimensions of 0.5 mm × 0.5 mm × 0.5 mm. Each voxel accumulated deposited energy, which was converted to absorbed dose by normalizing to the voxel mass, calculated as the product of phantom density and voxel volume. The mesh covered a physical half-size of 25 mm in each spatial dimension, resulting in a total mesh mass of approximately 50 g.

From this mesh configuration, three-dimensional dose maps were extracted, and two-dimensional dose distributions were subsequently presented. Dose profiles were also generated along relevant spatial axes to further characterize the dose gradients.

Additionally, two cubic water-equivalent dosimeters of 1 mm and 5 mm side lengths were simulated to evaluate dose deposition at discrete, clinically relevant volume sizes. These dosimeters function as point-dose detectors and provide data along radial and axial directions relative to the catheter, thereby validating the voxel-based dose calculations and enabling direct comparison with analytical models.

4.6 Statistical Analysis

All Monte Carlo simulations were performed with sufficiently large numbers of primary particle histories to ensure statistically robust dose estimates. Statistical uncertainties in dose calculations were quantified by determining the standard deviation of deposited energy within each scoring voxel or detector volume and normalizing by the mean deposited energy, thereby expressing relative uncertainties as percentages. The number of simulated particle histories was chosen to maintain these uncertainties below 2% in clinically relevant regions, particularly within and adjacent to the SISLOT catheter's active volume, ensuring high confidence in the spatial dose distributions obtained.

Simulation output data were processed using a custom R script that parsed raw data files alongside simulation configuration parameters, such as voxel dimensions, mesh boundaries, and scoring geometry. This script automated the extraction and aggregation of deposited energy values, calculation of absorbed doses normalized to voxel mass and phantom density, and computation of statistical metrics including mean dose, standard deviation, and relative uncertainties. By integrating simulation results with mesh parameters programmatically, the R script enabled efficient data handling and comprehensive dose analysis across the entire scoring volume. This streamlined approach facilitated assessment of dosimetric homogeneity, identification of dose gradients, and comparison of multiple geometric configurations with minimal manual intervention.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interest

SC is co-owner of several patents on the construction and development of the SISLOT system.

Funding Declaration

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Bibliography

1. **Nath R, Anderson LL, Luxton G, et al.**
Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No. 43.
Med Phys. **22**(2):209–234 (1995).

2. **Rivard MJ.**
Dosimetry for beta-emitting brachytherapy sources.
Brachytherapy. **21**(6 Suppl):S30–S31 (2022).

3. **Mumper RJ, Ryo UY, Jay M.**
Neutron-activated holmium-166–poly(L-lactic acid) microspheres: a potential agent for the internal radiation therapy of hepatic tumors.
J Nucl Med. **32**(11):2139–2143 (1991).

4. **Agostinelli S, Allison J, Amako K, et al.**
Geant4—a simulation toolkit.
Nucl Instrum Methods Phys Res A. **506**:250–303 (2003).

5. **Allison J, Amako K, Apostolakis J, et al.**
Geant4 developments and applications.
IEEE Trans Nucl Sci. **53**(1):270–278 (2006).

6. **Allison J, Amako K, Apostolakis J, et al.**
Recent developments in Geant4.
Nucl Instrum Methods Phys Res A. **835**:186–225 (2016).

7. **Chauvie S, Depaola G, Ivanchenko VN, et al.**
Geant4 low energy electromagnetic physics.
In: *Proceedings of the Computing in High Energy and Nuclear Physics Conference (CHEP 2001)*; Beijing, China; 3–7 September 2001.

8. **Tuli JK.**
Evaluated nuclear structure data file.
Nucl Instrum Methods Phys Res A. **369**(2–3):506–510 (1996).

9. **Weber M, Lam MGEH, et al.**
EANM procedure guideline for the treatment of liver cancer and liver metastases with intra-arterial radioembolization.
Eur J Nucl Med Mol Imaging. **49**(5):1682–1699 (2022).

10. **Reinders MTM, et al.**
Holmium-166 radioembolisation dosimetry in hepatocellular carcinoma.
Eur J Nucl Med Mol Imaging. **52**:993–1003 (2025).

11. **Nikjoo H, Uehara S, Cucinotta FA.**
Track-structure codes in radiation research.
Radiat Meas. **41**:1052–1074 (2006).

12. **Graves SA, Flynn TR, Hyer DE.**
Dose point kernels for 2,174 radionuclides.
Med Phys. **46**(11):5284–5293 (2019).

13. **Westlund Gotby LEL, Stella M, Van Speybroeck CDE, et al.**
Towards harmonized holmium-166 SPECT image quality for dosimetry: a multi-center, multi-vendor study.
EJNMMI Phys. **12**:24 (2025).

14. **Herrmann K, Schwaiger M, Lewis JS, et al.**
Radiotheranostics: a roadmap for future development.
Lancet Oncol. **21**(3):e146–e156 (2020).

15. **Auditore L, Amato E, Pistone D, et al.**
The contribution of internal bremsstrahlung to the ^90Y dose point kernel.
Med Phys. **50**(3):1865–1870 (2023).

16. **Italiano A, Pistone D, Amato E, et al.**
Internal bremsstrahlung, the missing process in beta-decay Monte Carlo simulation: the relevance in ^32P dose-point-kernel estimation.
Phys Med. **110**:102585 (2023).

Figure 1. Pictorial representation the spiral SISLOT catheter to be positioned in close proximity to the tumour.

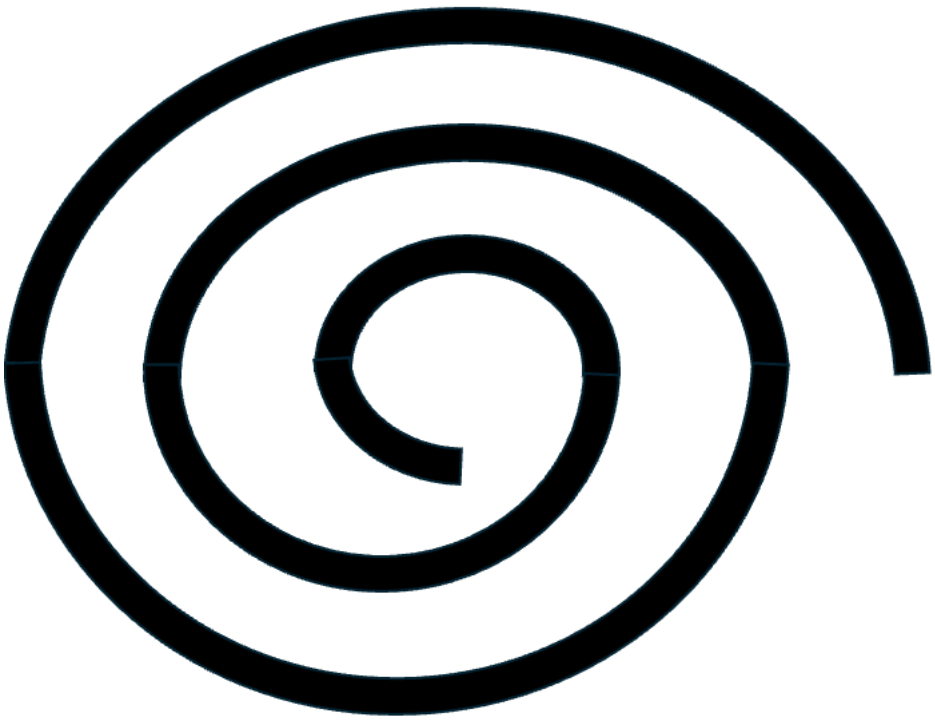


Figure 2. Geometry of the SISLOT catheter as describe in the text (axial slice of 1 cm).

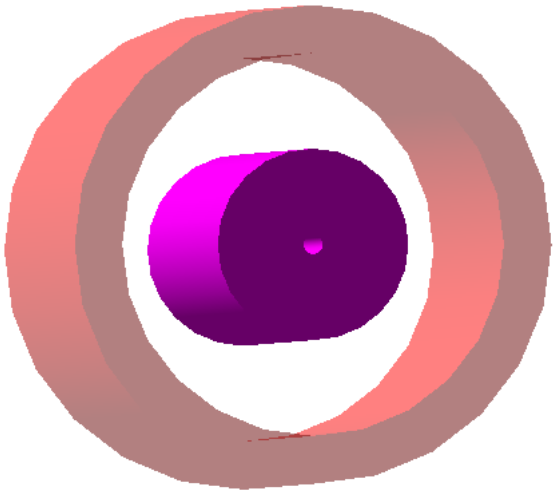


Figure 3. Dose distribution around the spiral involvement of the SISLOT catheter

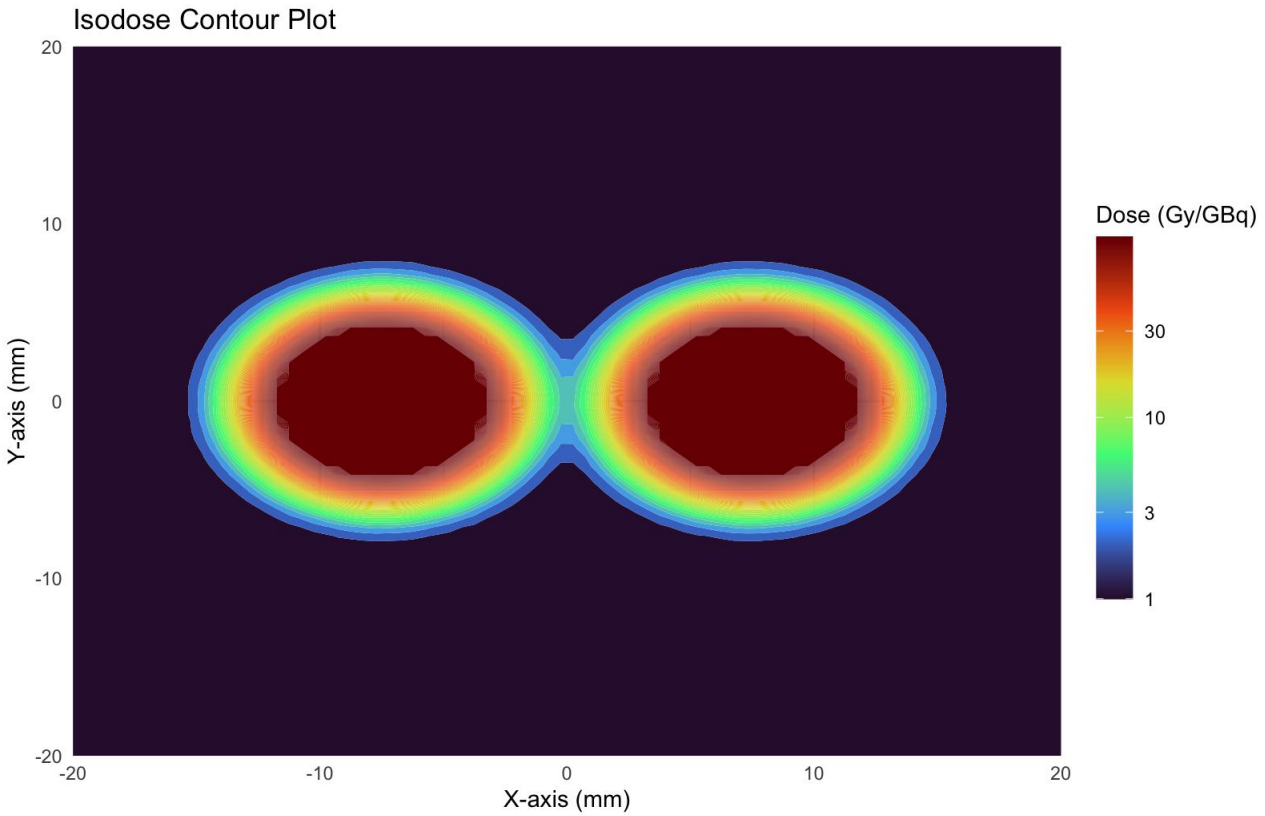


Figure 4. Logarithm of dose along the central axis of the spiral of SISLOT catheter.

