RadCalc Classic: The Original Comprehensive Secondary Dose Calculation Software for Radiation Therapy

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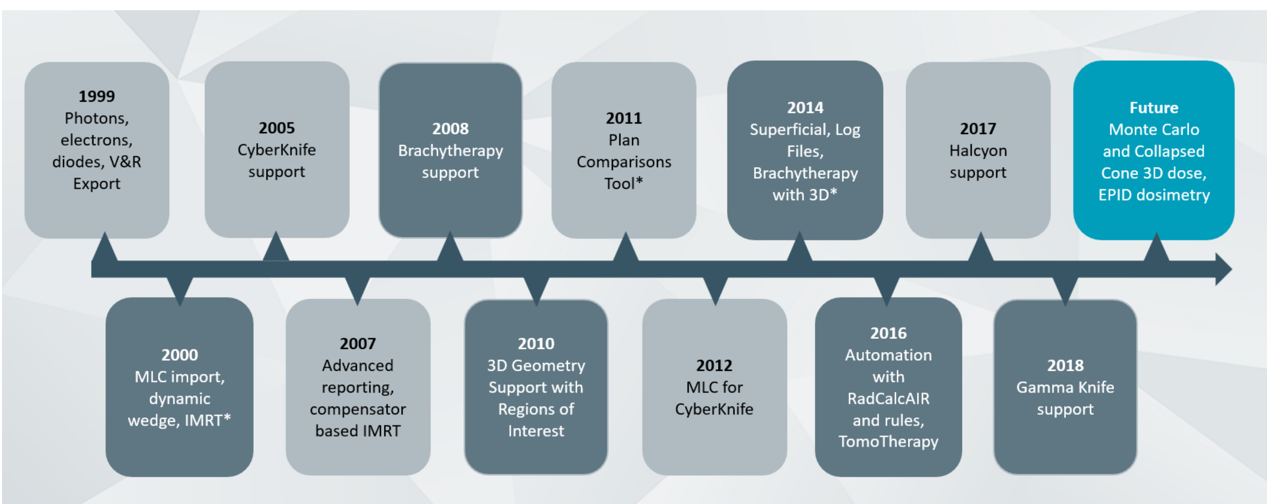
This whitepaper explores RadCalc's evolution, showcasing its robust features like monitor unit, time, and dose calculations; enhancing workflow efficiency and reducing errors. Delve into the modular design that supports diverse treatment modalities, including IMRT, BrachyTherapy, Superficial, TomoTherapy, and Gamma Knife. Extensive clinical evaluations have validated RadCalc's accuracy and reliability, making it an indispensable tool for ensuring patient safety and treatment efficacy. Read on to understand why RadCalc is trusted by clinicians for delivering precise and effective cancer treatments.

A History of Innovation



* First to market with these products

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1.1 Introduction

RadCalc is a specialized software program that provides secondary dose calculation calculations (SDC) for radiation therapy treatments. It plays a crucial role in validating the radiation dose to be administered to patients, ensuring accuracy and safety in radiation therapy. RadCalc performs calculations for Monitor Units (MU), time, or actual dose in Gray (Gy) or centi-Gray (cGy), supporting photon, superficial, brachytherapy, and electron beams. While it does not directly control radiation hardware, RadCalc interfaces seamlessly with primary radiation therapy planning software and verify-and-record systems.

Safety is a priority in radiation therapy. Protecting patients against ionizing radiation to healthy tissue is essential; every measurement must be as accurate as possible. Various QA processes can produce different results, making verifying calculations independently a second time imperative. This is exactly what RadCalc does: it independently verifies dosimetric calculations in an easy-to-use software platform.

1.2 Key Features of RadCalc

RadCalc enhances clinical practice by providing advanced tools for precise and efficient verification. Its seamless integration with treatment planning systems optimizes workflow efficiency, enabling clinicians to concentrate on patient care.

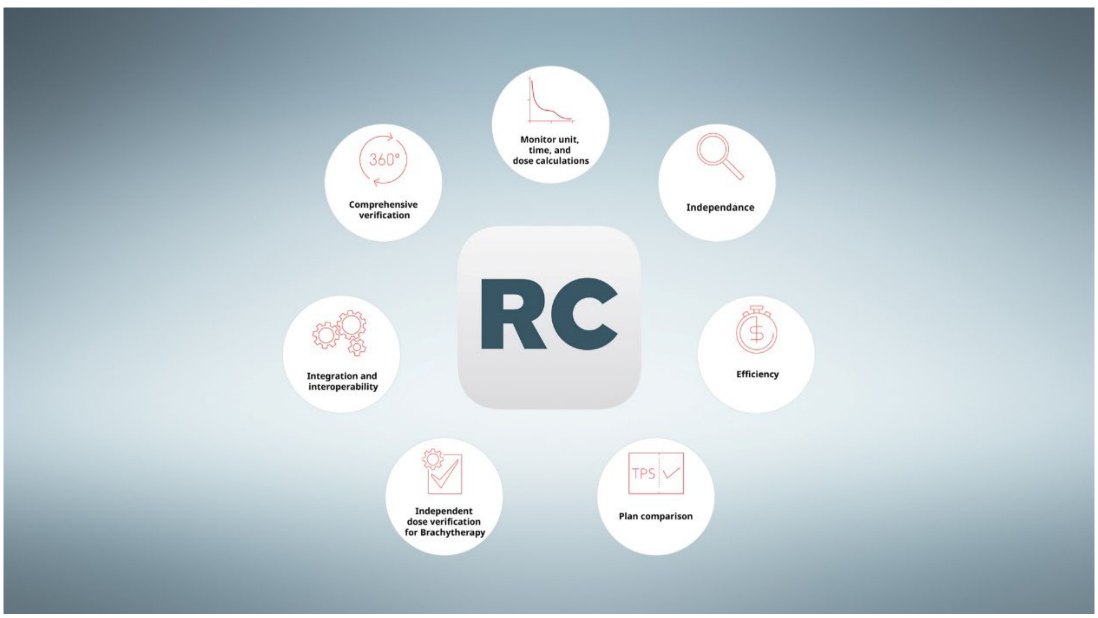

Image 1 RadCalc key features overview

Monitor Unit, Time, and Dose Calculations

RadCalc excels in performing an SDC via calculating monitor units, treatment time, and dose through data retrieved from input tables or curves, and through models that characterize this data. These calculations are critical for validating the outputs of primary radiation therapy planning systems, ensuring accurate and precise treatment delivery. By providing these calculations, RadCalc supports the accuracy and reliability of radiation therapy treatments, which is paramount for patient safety.

Independence

RadCalc provides multiple levels of independence, ensuring the highest levels of accuracy and safety in radiation therapy. Independence in the measured data, positioning and fluence generation, and calculation methods. By performing these independent calculations, RadCalc reduces the risk of errors and enhances the overall quality assurance process.

Efficiency

RadCalc features automated data import and export capabilities with RadCalcAIR, streamlining the workflow and reducing the need for manual data entry. This automation minimizes the potential for errors, increases productivity, and allows clinicians to focus more on patient care rather than administrative tasks. The value of optimizing the workflows in the clinic are demonstrated in the reduced bunker time need and reduced hours staff is performing repetitive tasks.

Plan Comparison

One of RadCalc's unique features is its plan comparison capability. This allows users to compare the plan from the Record & Verify (R&V) system with the plan data directly exported from the Treatment Planning System (TPS). This comparison is essential for discovering data transfer errors between an approved plan in the TPS and the plan residing in the R&V prepared for delivery. This feature is particularly useful for identifying discrepancies and ensuring that the final treatment plan is accurate and reliable.

Brachytherapy Independent Plan Verification

RadCalc offers independent dose verification and source positioning for a variety of brachytherapy treatments, including High Dose Rate (HDR), Low Dose Rate (LDR), and permanent implant brachytherapy. It enhances this capability by providing 3D dose and Dose Volume Histogram (DVH) information for comprehensive analysis. This feature ensures that all brachytherapy treatments are thoroughly validated for accuracy, offering clinicians confidence in the treatment plans.

Integration and Interoperability

RadCalc seamlessly integrates with various treatment planning systems (TPS), providing a versatile and comprehensive solution for dose verification. Its interoperability ensures that RadCalc can easily consume data from different TPS, making it a valuable tool for any radiation oncology department. This seamless integration streamlines workflows and enhances the efficiency of the treatment planning and verification process.

Comprehensive Vendor Agnostic Verification

With support for a wide range of treatment types and modalities, including Intensity-Modulated Radiation Therapy (IMRT), TomoTherapy, Gamma Knife, and brachytherapy, RadCalc offers comprehensive dose verification capabilities. This broad support ensures that all treatment plans, regardless of their complexity, are accurately verified. RadCalc's comprehensive verification capabilities make it an indispensable tool for ensuring the quality and safety of radiation therapy treatments.

1.3 Supported modalities via several modules

RadCalc is modular, offering specific modules tailored to various aspects of radiation therapy verification:

RadCalc Base The core module of RadCalc performs all calculation verifications, ensuring accurate secondary dose checks for radiation therapy treatments..	**Treatment Plan (RTP) Import** This module allows for the seamless import of treatment plans directly from the primary treatment planning software, eliminating the need for manual data entry and reducing the potential for errors.	**Verify and Record Export** RadCalc can export the verified radiation treatment plan to the verify-and-record system, streamlining the workflow and ensuring consistency in treatment documentation.
IMRT Module This module verifies calculations for Intensity-Modulated Radiation Therapy (IMRT) treatments, ensuring precision in complex dose distributions and enhancing the accuracy of the treatment delivery.	**Brachytherapy Module** RadCalc performs independent dose verification calculations for brachytherapy treatments, supporting HDR, LDR, and permanent implants. It includes tools for 3D dose and Dose Volume Histogram (DVH) analysis, providing comprehensive verification.	**Regions of Interest for 3D Geometry** By importing regions of interest from the planning system via DICOM RT or Pinnacle, this module computes depths and effective depths to points of calculation, enhancing dose accuracy and ensuring precise treatment delivery.
Superficial Module RadCalc allows the definition of multiple energies with individual HVL values and energy specific parameters. Every energy can have a list of allowed SSDs, cones and measured backscatter factors.	**TomoTherapy Module** RadCalc supports TomoHelical, TomoDirect and TomoEDGE and verifies the treatment time and dose to multiple calculation points.	**Gamma Knife Module** RadCalc performs point dose verification calculations for various Gamma Knife versions and the Leksell GammaPlan (LGP) planning system.

1.4 Clinical Evaluation Evidence

RadCalc has a long-standing history of clinical excellence since its first release in 1999. Initially developed to meet the stringent recommendations of TG-40[1], RadCalc was designed to provide comprehensive secondary dose checks with an expected agreement of better than +/- 5.0%. Over the years, RadCalc has continuously evolved, incorporating new recommendations from the American Association of Physicists in Medicine (AAPM) to enhance its accuracy and reliability.

Despite the evolving standards, the foundational criteria of achieving agreements within +/- 5.0% have remained a benchmark, ensuring consistency in its performance. The development team at RadCalc has always aimed to tighten these criteria as much as possible, striving for the highest levels of precision in dose verification. This commitment to accuracy is reflected in the robust clinical evaluations and consistent performance improvements seen in RadCalc's subsequent versions.

By integrating these rigorous standards and adapting to new guidelines, RadCalc has solidified its reputation as a trusted and reliable tool in radiation therapy, ensuring that patients receive the safest and most effective treatments possible.

1.4.1 RadCalc Base, Treatment Plan (RTP) Import and Verify and Record Export Modules

The Original RadCalc

The RadCalc Base, Treatment Plan (RTP) Import and Verify and Record Export modules were the first to be released in 1999, laying the foundation for RadCalc's comprehensive dose verification capabilities. The RadCalc Base module was specifically designed to perform a 2D Monitor Unit (MU) calculation for 3D Treatment Planning Systems (TPS). The desired accuracy for these calculations was set within an acceptable criteria of +/- 3.0%. This threshold was considered acceptable because RadCalc's 2D calculations, while reliable, originally did not account for scattered radiation within a patient as comprehensively as the 3D computations performed by modern TPS. Early versions of RadCalc simplified the patient model to a rectangular or square phantom, focusing on verifying the primary TPS's computation of monitor units rather than modeling complex patient anatomies. This approach was in line with the guidelines later described in TG-114[2].

Alongside providing secondary dose checks, the Treatment Plan (RTP) Import and Verify and Record Export modules enhanced accuracy and efficiency by automatically importing and facilitating transfer to the R&V of 33 key parameters for photon calculations. This automation significantly reduced the potential for human error. The parameters imported the following:

- Prescription name
- Prescribed dose
- Number of fractions for prescription
- Accelerator name
- Energy
- Dose per treatment for field
- Isodose at calculation point
- Dose at calculation point
- Gantry mode/direction
- Gantry start/stop angles
- Collimator angle
- Couch angle

- X jaw mode and X1 & X2 jaw settings
- Y jaw mode and Y1 & Y2 jaw settings
- Wedge name/orientation
- Tray name/factor
- Use of compensator/factor
- Equivalent square at isocenter
- Collimator output factor (OFc)
- SSD at calculation point
- Inverse square factor
- Off-axis distance in X-direction (OADx)
- Off-axis distance in Z-direction (OADz)

- Off-axis factor (OAF)
- Blocked equivalent square at calculation point
- Phantom output factor (OFp)
- Tissue phantom ratio (TPR)
- Calibration at isocenter
- Dose per monitor unit
- Monitor units
- Plan monitor units
- Percent difference computation
- Acceptable monitor unit calculation

1.4.2 The IMRT module and additional support for in vivo TLD/Diode and Electrons deliveries

Enhancements in RadCalc v4.0

Just one year later in 2000, RadCalc version 4.0 introduced significant enhancements including support for electron and TLD/Diode calculations, further expanding the capabilities of the RadCalc Base module. The electron calculation support was implemented similarly to the photon calculations, adhering to the guidelines described in TG-114 and other relevant publications[2, 3, 4]. This enhancement included the automatic import of 11 parameters for electron calculations within the Treatment Plan (RTP) module:

- Number of fractions for prescription
- Isodose to treat/normalized PDD
- Depth of treatment
- X jaw setting

- Y jaw setting
- Cone factor
- Cutout factor
- Inverse square factor

- Calibration factor
- Dose per monitor unit
- Monitor units

The addition of in-vivo TLD/Diode computations in RadCalc v4.0 introduced two crucial functions. The first function calculates the dose at the Dmax depth for a beam. The second function takes an input TLD or diode reading and applies a series of correction factors to this reading based on the beam arrangement, as detailed in TG-62 (report 87)[5]. This process results in a measured dose value for the patient. Seven parameters were added for the import of in-vivo TLD/Diode calculations:

- Inverse square correction factor
- SSD correction factor
- Field size correction factor

- Attenuator correction factor
- Wedge correction factor

- Off-axis correction factor
- Measured dose

When the Electron module was first introduced, the results were shown to be exact due to the manual methods used for treatment planning. All results were within the acceptance criteria for the measured dose calculations with TLD/Diode measurements. Most values were derived from factors in the database, requiring interpolation only for the off-axis, field size, and SSD corrections.

Introduction of the IMRT Module

The introduction of the Intensity-Modulated Radiotherapy (IMRT) module in RadCalc utilized the Modified Clarkson Integration (MCI) algorithm for dose calculations. This algorithm, tested and published in the Medical Physics journal[6], involves thousands of calculations that cannot be computed manually. To validate the MCI algorithm, clinical data from treatment planning systems were exported and computed. The largest disagreement in these calculations were observed in a head and neck cases with many sloping surfaces. This discrepancy arose because RadCalc at this point still simplified the patient model to assume the patient surface is flat at each beam angle, potentially overestimating the scatter contribution and, consequently, the dose. Despite this, the percent difference was considered acceptable in a clinical setting, providing confidence in the primary treatment planning system's efficacy.

1.4.3 The Brachytherapy Module

Introduction of RadCalc v6.0 Brachytherapy Module

in 2008, RadCalc version 6.0 marked a significant milestone with the introduction of the Brachytherapy module, based on the AAPM TG-43 protocol and supplementary publications[7, 8, 9]. This module was designed to compare the calculated doses from treatment planning systems that also adhere to the TG-43 protocol. The Brachytherapy module imported and evaluated five main parameters:

- Source Strength Decay Calculation
- Geometry Factor Calculation

- Radial Dose Factor Calculation
- Anisotropy Factor Calculation

- Point Dose Calculations

To ensure the module's accuracy, treatment plans from the Varian BrachyVision and Oncentra Brachytherapy treatment planning systems were used for testing. These treatment plans were either exported from the primary treatment planning system via DICOM RT or manually entered into RadCalc.

All calculations performed by RadCalc were within the acceptable criteria of 5% difference from the treatment planning systems. The larger deviations observed in calculations were from larger angles of incidence between the point of calculation and the radioactive sources. These discrepancies are more sensitive to interpolation methods and the determination of the angle of incidence. Differences in interpolation methods used by the TPS were taken into consideration.

1.4.4 The Regions of Interest (ROI) Module

3D Geometry Support with Regions of Interest Module in Version 6.1

The Regions of Interest (ROI) Module in RadCalc was introduced in 2010 and was the evolution of utilizing a simplified the patient model to an elegant light three-dimensional patient model to enable RadCalc to calculate depth and equivalent path values for beams and control points used in calculating monitor units or dose for external beam radiation. This evolution in turn enabled the ability for RadCalc to calculate depth values per control point for Volumetric Modulated Arc Therapy (VMAT).

Testing for regions of interest calculations was done using Varian’s RapidArc planning tool and Pinnacle’s SmartArc.

The following table provides a detailed comparison of percent agreement for RadCalc versions 5.2 and 6.1, with and without body contour:

Patient #	RadCalc Version 5.2 % agreement				RadCalc Version 6.1 % agreement w/o body contour				RadCalc Version 6.1 % agreement with body contour			
	First Course		Cone Down		First Course		Cone Down		First Course		Cone Down	
	CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW
1.	-0.5	-4.9	-7.8	-1.2	0.4	-1.2	-5.4	0.1	-1.2	0.2	-1.8	0.0
2.	IMRT	IMRT	-3.0	-6.4	IMRT	IMRT	-	-4.8	IMRT	IMRT	-	-0.1
3.	-4.0	-7.3	N/A	N/A	-	-6.3	N/A	N/A	-	0.0	N/A	N/A
4.	IMRT	IMRT	-4.3	-7.7	IMRT	IMRT	-	-6.7	IMRT	IMRT	-	-1.0
5.	-7.4	-2.6	N/A	N/A	-6.4	-	N/A	N/A	-0.4	-	N/A	N/A
6.	-0.4	-5.7	N/A	N/A	-	-5.5	N/A	N/A	-	-0.4	N/A	N/A
7.	3D	3D	-3.1	-10.9	3D	3D	-2.3	-5.5	3D	3D	0.5	-3.5
8.	-8.0	-9.0	N/A	N/A	-6.3	-8.2	N/A	N/A	-0.1	-1.5	N/A	N/A
9.	-4.0	-5.1	N/A	N/A	-1.3	-4.2	N/A	N/A	-0.1	0.0	N/A	N/A
10.	-3.2	-5.0	N/A	N/A	-0.5	-3.7	N/A	N/A	0.5	-0.3	N/A	N/A
11.	IMRT	IMRT	-6.6	-3.2	IMRT	IMRT	-4.3	-0.7	IMRT	IMRT	-1.3	-0.4
12.	IMRT	IMRT	-5.9	-5.4	IMRT	IMRT	-4.2	-4.1	IMRT	IMRT	-4.1	-2.0
13.	-6.0	-8.8	N/A	N/A	-3.8	-3.3	N/A	N/A	0.3	1.2	N/A	N/A
14.	-7.6	-4.4	N/A	N/A	-2.2	-1.4	N/A	N/A	-1.1	0.0	N/A	N/A

Table 1: Wherever N/A is stated then VMAT calculations were not performed. The data was examined with and without using the ROI Module. This was done to note the difference between using and not using the ROI module. It also demonstrated the differences between the changes in version 6.1, where some corrections were made to how multiple control point calculations were done when using arcs. With regard to version 5.2 and 6.1 without body contour results, an average depth and average effective depth were used as computed by the planning system.

As demonstrated in Table 1, there was an improvement in the percent agreement between version 5.2 calculations and 6.1 calculations without the body contour. For calculations in version 6.1 with the body contour agreement was even better. The average agreement in version 5.2 was -5.3%; in version 6.1 without the body contour, the average was -3.7%, and in version 6.1 with the body contour, the average percent difference was -0.7%. There is significant improvement in dose calculation when using the patient contours to calculate VMAT treatments.

1.4.5 The Superficial Module and Support for 3D Brachytherapy and Image Analysis

Features to the RadCalc Base and Brachytherapy Modules

In 2014, RadCalc version 6.3 introduced several significant enhancements, expanding the capabilities of the RadCalc Base and Brachytherapy modules. These enhancements include support for superficial/orthovoltage calculations, the ability to compute and display 3D dose volumes for brachytherapy, and new image analysis functionality. While these features may seem complex and described in literature [10, 11], their implementation leveraged existing, thoroughly evaluated functionality within RadCalc.

Superficial/Orthovoltage Calculations

The addition of superficial/orthovoltage calculations to the RadCalc Base module allows users to perform these types of calculations with the same accuracy and reliability as other RadCalc calculations. This extension ensures that RadCalc can be used for a broader range of treatments, enhancing its utility in clinical settings.

3D Brachytherapy Dose Volumes

Version 6.3 also added the ability to compute and display 3D dose volumes for Brachytherapy calculations. This feature involves generating a collection of points distributed in a uniform grid-like pattern, representing the dose distribution in three dimensions. This enhancement provides a more comprehensive view of dose distribution, allowing for better treatment planning and verification.

Image Analysis Functionality

The new image analysis functionality introduced in RadCalc v6.3 is a valuable tool for quality assurance in radiation therapy. RadCalc has historically generated or imported fluence maps for compensator-based IMRT. The new functionality allows for the mathematical comparison of two fluence maps or dose maps through three main processes:

Percentage Difference Calculation
This routine process calculates the percentage difference between two dose values, similar to existing RadCalc functionality for comparing monitor units or dose values.

Distance to Agreement (DTA)
This value is determined by searching the dose or fluence to other point locations until finding a value within a specified percentage. It is akin to the volume average dose tool used for IMRT calculations in RadCalc.

Gamma Analysis
This mathematical formula combines two values to provide an overall quality index, offering a comprehensive comparison of fluence or dose maps.

These image analysis features provide a simple yet effective way for users to assess how well two maps (i.e., fluence or dose) match, enhancing the accuracy and reliability of quality assurance procedures.

1.4.6 The TomoTherapy Module

Introduction of RadCalc v6.3.4 TomoTherapy Module

Support for plans produced for delivery on TomoTherapy systems was introduced in 2016 with version 6.3.4 and testing was conducted on over one hundred calculations. The results demonstrated high accuracy, with none of the calculations exceeding the acceptance criteria of 5% difference. However, on average, the calculations showed a percentage difference of 1% or less. These results indicate that RadCalc's TomoTherapy module provides reliable and precise dose calculations, comparable to other systems in the field [(12)]. The consistency and accuracy of these calculations support the module's efficacy in clinical settings, ensuring that TomoTherapy treatments are accurately verified and safe for patients.

1.4.7 The Gamma Knife Module

Introduction of RadCalc v6.4.1.0 Gamma Knife Module

RadCalc version 6.4.1.0 introduced the capability to perform Gamma Knife calculations int 2018, expanding the software's dose verification functionalities. The Gamma Knife calculations leverage existing RadCalc features, such as ray tracing through regions of interest, various computational capabilities, and visualization tools. Additionally, the module includes new functionality for importing plan information via an SQL database connection, along with minor computational enhancements for data storage and table lookups.

Extensive testing was conducted to evaluate the accuracy of the Gamma Knife calculations in RadCalc v6.4.1.0. Out of approximately 1050 total calculations, only three calculations were more than 5% off, meeting the criteria for acceptance. Additionally, only seven calculations showed more than a 3% discrepancy. Consequently, 99.3% of all calculations were within a 3% difference, demonstrating a high level of accuracy.

The results indicate that the Gamma Knife module provides reliable and precise dose calculations, suitable for use as a secondary dose verification tool. The few outliers observed were primarily at shallow depths, consistent with findings in relevant literature[(13)].

1.5 Conclusion

RadCalc stands as an indispensable tool for radiation therapy professionals, offering reliable secondary dose calculations that ensure the accuracy and safety of treatment delivery. Its modular design provides the flexibility and scalability necessary to meet the diverse needs of modern radiation therapy practices. By seamlessly integrating with existing systems and delivering robust verification features, RadCalc significantly enhances the quality and safety of radiation treatments for cancer patients.

Extensive clinical evaluations and rigorous testing have consistently validated the efficacy and reliability of RadCalc across its various versions and modules. These evaluations demonstrate RadCalc's commitment to maintaining high standards in the field of radiation therapy, ensuring continued excellence and trust among its users. Through its advanced capabilities and user-centric design, RadCalc remains a vital component in the pursuit of effective and precise cancer treatments, supporting clinicians in delivering the best possible care to their patients.

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