# DoseCHECK™ & PerFRACTION™

## On the Accuracy of the SNC Dose Calculator Algorithm

SUN NUCLEAR corporation

# Introduction

## Sun Nuclear Corporation (SNC) patient QA products PerFRACTION™ and DoseCHECK™ utilize an advanced dose calculation engine that is new and unique in the radiation therapy market.

Whereas the intended purpose of the two products is different - PerFRACTION uses the SNC Dose Calculator (SDC) for pre-treatment QA (Fraction 0™) and in vivo QA (Fraction n™) while DoseCHECK uses the SDC to produce an entire dose volume to check against that from the Treatment Planning System (TPS) - both products pass the same required inputs to the SDC and receive a full 3D dose volume in return. As with the introduction of any new radiotherapy dose calculation engine, one of the first questions that comes to the responsible clinical physicist's mind is, "How accurate is the dose calculation?" This white paper will answer that question and, in doing so, establish a baseline accuracy for the SDC.

# Dose Calculator Algorithm in Brief

## Before describing the methods and results of this accuracy study, it is useful to briefly describe how the dose calculation engine works.

A more thorough description is available in the appendix for the interested reader. The SDC is a collapsed-cone convolution/superposition (C/S) algorithm[1,2] developed at The Johns Hopkins University.[3,4] The algorithm shares some of the same general themes of other C/S algorithms on the market, such as the same core steps involved in the calculation, namely:

1. Fluence Calculation (radiation transport within the accelerator head)
2. TERMA Calculation (radiation transport from the accelerator to the patient)
3. Superposition (radiation transport within the patient).

However the algorithm is quite unique in that it offers several advantages through its patent-protected[5] graphical processor unit (GPU) acceleration technology. Most notable among these advantages is the inverse ray trace performed for the TERMA calculation and the inverse dose deposition during the superposition step, both of which are calculated in the GPU to take advantage of the massively parallel nature of these computational processes. Further, it is these performance gains that make other advantages possible that have heretofore not been possible due to computational limitations, such as:

- True dual-source model, each with their own spectrum and radial intensity definition (step 1)
- Explicit modeling of MLC parameters (step 1)
- Precise ray-tracing across boundaries while accounting for multiple material types and spectral changes during the TERMA computation (step 2)
- Kernel tilting, kernel hardening, and cumulative-cumulative kernel approach (step 3).

These are highlights of the algorithm; further details can be found in the appendix.

# Methods

## At the highest level, this study involved four different comparisons of results from the SDC (version 1.0.1), including:

1. Ion chamber measurements
2. ArcCHECK™ measurements
3. ArcCHECK Planned Dose Perturbation (ACPDP) reconstructed dose
4. Treatment Planning System dose volume.

All studies and analyses were conducted at The H. Lee Moffitt Cancer Center, by Saeed Ahmed and Vladimir Feygelman. Details regarding the systems and instruments used for study are contained in Table 1.

*Table 1: System/Instrument Details*

| System/Instrument | Type/Version Used |
|---|---|
| Treatment Planning System | Pinnacle$^3$ (version 9.8) |
| Delivery System and Beam Energy | Varian TrueBeam™ (version 2.0), Millennium 120 MLC, 6 MV |
| Case Types Studied | Anal, Head & Neck, Abdomen, and Lung |
| Ion Chamber | PTW 0.125 cm$^3$ Model TN31010 |
| Homogenous Phantom | CIRS Plastic Water® Phantom |
| Anthropomorphic Phantom | CIRS IMRT Thorax Phantom |
| 3D Measurement Phantom | Sun Nuclear ArcCHECK (software version 6.6.2) |
| 3D Phantom Dose Reconstruction | Sun Nuclear 3DVH™ (version 3.2.0) ACPDP |

The four Case Types are from the AAPM TG-244 Report library of test plans.[6] Treatment plans were generated in Pinnacle for all four cases using a 6 MV, 10 FFF, and 15 MV beam (Varian TrueBeam). For three of the four cases (Anal, Head & Neck, Abdomen), QA plans were calculated into the Plastic Water (PW) phantom. For the final case (Lung), a QA plan was generated on the Thorax phantom. The four cases were delivered to their respective phantoms with the ion chamber inserted accordingly, and also to the ArcCHECK device. Results were then compared. This methods workflow is depicted below in Figure 1.

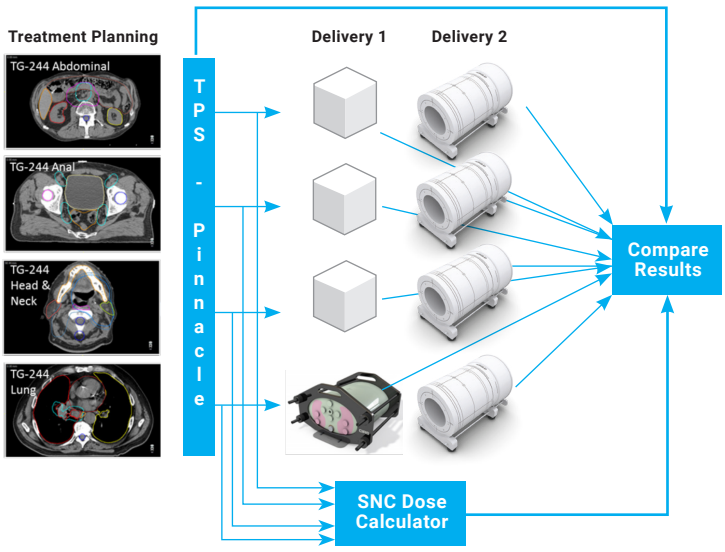


*Figure 1. Workflow followed for this study.*

# Results and Discussion

## SDC vs. Ion Chamber

The calculated point doses are compared to the ion chamber measurements in Table 2. The primary TPS data are also presented for completeness. The SDC exhibits 0.2% average deviation from the ion chamber, well within the 1.5% recommended by TG-244 for the primary TPS in the high dose low gradient area.

| | | | | 6 MV | | 10 FFF | | 15 MV | |
|---|---|---|---|---|---|---|---|---|---|
| **TG-244 Patient/Test** | **Phantom** | **Point** | **Plan** | **SDC - IC (%)** | **Pinn. - IC (%)** | **SDC - IC (%)** | **Pinn. - IC (%)** | **SDC - IC (%)** | **Pinn. - IC (%)** |
| ABDOMEN | PW Cube | Cube center | VMAT | 0.6 | 1.0 | 0.3 | 0.6 | 0.8 | 0.8 |
| | | | IMRT | 0.1 | -0.3 | -0.1 | -0.3 | -0.05 | -0.1 |
| Head & Neck | PW Cube | Cube center | VMAT | -0.9 | 1.0 | 0.4 | 1.0 | -0.3 | 0.6 |
| | | | WFIMRT | -0.4 | 1.2 | 0.9 | 1.1 | -0.8 | 0.6 |
| ANAL | PW Cube | Cube center | VMAT | -2.0 | 1.4 | -0.6 | -1.6 | -0.3 | 0.9 |
| | | | WFIMRT | -1.1 | 2.0 | 0.01 | 1.0 | -1.3 | 1.4 |
| LUNG | CIRS Thorax | Target | VMAT | 2.6 | 3.1 | 1.1 | 0.9 | 4.0 | 1.4 |
| | | | WFIMRT | 1.9 | 2.1 | 1.8 | 1.4 | 2.8 | 1.2 |
| | | "Mediastinum" | VMAT | 1.3 | 2.5 | -0.6 | -2.0 | -1.5 | -2.8 |
| | | | WFIMRT | 0.3 | 0.8 | -1.0 | -4.0 | -1.2 | -5.4 |
| | | | ***Average*** | ***0.2*** | ***1.5*** | ***0.2*** | ***-0.2*** | ***0.2*** | ***-0.1*** |
| | | | ***St. Dev.*** | ***1.4*** | ***1.0*** | ***0.9*** | ***1.8*** | ***1.8*** | ***2.2*** |

*Table 2. Relative local percent difference between calculations (the SDC and Pinnacle) and ion chamber measurements.*

## SDC vs. ArcCHECK

According to criteria in the upcoming AAPM TG-218 report, the tolerance limit (treatable but further evaluation may be warranted) should be set at 95% of points passing the 3% Global/2mm/10% gamma analysis , with the action limit set at 90% (requires additional analysis and may need corrective action). The SDC produces agreement with ArcCHECK above the tolerance limit in all the studied cases but one (Table 3). The γ passing rate is 93.5% for the wide-field IMRT Anal plan, still above the action limit of 90%. This is one of the most challenging plan classes computationally, combining large bifurcating targets (requires very accurate dose modeling under the MLC) with the wide-field technique that imposes rather stringent accuracy requirement on the leaf penumbra model in the TPS.

| | | 6 MV | | 10 FFF | | 15 MV | |
|---|---|---|---|---|---|---|---|
| **TG-244 Patient/Test** | **Plan** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** |
| ABDOMEN | VMAT | 100 | -1.3 | 100 | 0.7 | 100 | 0.9 |
| | IMRT | 99.1 | -1.3 | 98.0 | 1.3 | 99.0 | 0.6 |
| Head&Neck | VMAT | 99.7 | -2.2 | 98.6 | 2.9 | 99.9 | 1.0 |
| | WFIMRT | 98.6 | -2.5 | 96.7 | 2.0 | 98.8 | 0.03 |
| ANAL | VMAT | 99.2 | -3.4 | 98.2 | 1.9 | 99.5 | 0.4 |
| | WFIMRT | 93.5 | -3.4 | 97.3 | 1.5 | 98.2 | 0.04 |
| LUNG | VMAT | 99.8 | -0.5 | 96.0 | 3.4 | 98.3 | 2.3 |
| | WFIMRT | 99.1 | -1.5 | 94.5 | 1.9 | 97.6 | 0.8 |
| | ***Average*** | ***98.6*** | ***-2.0*** | ***97.4*** | ***2.0*** | ***98.9*** | ***0.8*** |
| | ***St. Dev.*** | ***2.1*** | ***1.0*** | ***1.7*** | ***0.9*** | ***0.9*** | ***0.7*** |

*Table 3. Gamma analysis (3% Global, 2mm) passing rates and median dose-difference (Global normalization) across all points: SDC vs. direct AC measurements.*

# SDC vs. MGDR

In the next step, the agreement between ArcCHECK PDP, a measurement-guided dose reconstruction on the patient dataset for which accuracy has been previously established[7,8] and the SDC follows the same trend as the direct comparison on the homogeneous phantom (Table 4). The only test case falling below the 95% agreement level is again the wide field IMRT Anal plan, for the same reasons as discussed above. The remaining ACPDP 3D doses for both VMAT and IMRT plans agree with the SDC for 96.4% of the points or better.

| | | 6 MV | | 10 FFF | | 15 MV | |
|---|---|---|---|---|---|---|---|
| **TG-244 Patient/Test** | **Plan** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-AC, %)** |
| ABDOMEN | VMAT | 99.9 | -0.5 | 98.9 | -0.3 | 99.7 | 0.29 |
| | IMRT | 99.9 | -0.3 | 99.6 | 1.0 | 100 | 0.26 |
| Head&Neck | VMAT | 98.2 | -1.0 | 96.3 | 2.6 | 99.1 | 0.6 |
| | WFIMRT | 98.9 | 0.1 | 95.9 | 2.7 | 98.7 | 0.2 |
| ANAL | VMAT | 96.4 | -3.0 | 99.0 | 1.5 | 99.5 | -1.53 |
| | WFIMRT | 91.8 | -3.2 | 98.7 | 1.2 | 97.0 | -2.18 |
| LUNG | VMAT | 98.1 | 0.5 | 90.4 | 4.3 | 90.9 | 2.6 |
| | WFIMRT | 98.6 | 0.7 | 94.5 | 3.1 | 95.8 | 1.7 |
| | ***Average*** | ***97.7*** | ***-0.8*** | ***96.7*** | ***2.0*** | ***97.6*** | ***0.2*** |
| | ***St. Dev.*** | ***2.6*** | ***1.5*** | ***3.1*** | ***1.4*** | ***3.1*** | ***1.6*** |

*Table 4. Gamma analysis (3% Global, 2mm) passing rates and median dose-difference (Global normalization) across all points: SDC vs. 3D measurement guided dose reconstruction on the patient dataset (ACPDP).*

# SDC vs. Pinnacle

Finally, the doses generated by Pinnacle and SDC are quantitatively compared in Table 5. Gamma analysis passing rates are well above 95% for all cases.

| | | 6 MV | | 10 FFF | | 15 MV | |
|---|---|---|---|---|---|---|---|
| **TG-244 Patient/Test** | **Plan** | **SDC Pass rate (%)** | **Median ΔD (SDC-TPS, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-TPS, %)** | **SDC Pass rate (%)** | **Median ΔD (SDC-TPS, %)** |
| ABDOMEN | VMAT | 99.9 | -0.02 | 99.3 | 0.4 | 99.8 | 1.07 |
| | IMRT | 100.0 | 0.5 | 99.9 | 0.9 | 100 | 1.43 |
| Head&Neck | VMAT | 99.8 | -0.8 | 98.7 | 2.3 | 97.5 | 1.5 |
| | WFIMRT | 99.8 | -0.1 | 97.7 | 3.2 | 96.3 | 2.0 |
| ANAL | VMAT | 99.9 | -0.5 | 98.7 | 2.0 | 99.1 | 1.05 |
| | WFIMRT | 99.8 | 0.0 | 98.8 | 2.8 | 99.7 | 1.35 |
| LUNG | VMAT | 100.0 | 1.3 | 98.9 | 3.8 | 93.4 | 4.9 |
| | WFIMRT | 99.8 | 1.8 | 98.6 | 3.4 | 96.3 | 3.7 |
| | ***Average*** | ***99.9*** | ***0.3*** | ***98.8*** | ***2.4*** | ***97.8*** | ***2.1*** |
| | ***St. Dev.*** | ***0.1*** | ***0.9*** | ***0.6*** | ***1.2*** | ***2.3*** | ***1.4*** |

*Table 5. Gamma analysis (3% Global, 2mm) passing rates with different dose-error thresholds and normalizations, and median dose-differences: SDC vs. Pinnacle.*

# Conclusions

Comparisons between the SDC and direct measurements (ion chamber and diode array), as well as with semi-empirical volumetric dose reconstruction (ACPDP), indicate that the SDC performs at the accuracy level expected from a primary TPS, on rather challenging cases. This is based on the TG-244 expectation of the mean dose disagreement with the ion chamber not exceeding 1.5% and the emerging routine patient QA standard of 95% of the dose distribution passing the γ(3% Global, 2mm, 10%) analysis.

# References

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# Appendix

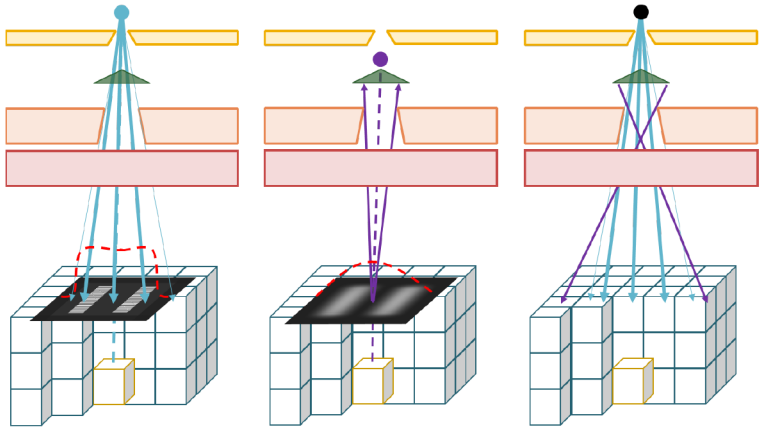
The dose calculator evaluated in this study was the SNC Dose Calculator (SDC) used in the PerFRACTION™ and DoseCHECK™ products from Sun Nuclear Corporation (Melbourne, FL). This dose calculator employs a collapsed-cone convolution/superposition (C/S) style dose calculation. The dose calculation consists of three steps:

1. Fluence Calculation (radiation transport within the accelerator head)
2. TERMA Calculation (radiation transport from the accelerator to the patient)
3. Superposition (radiation transport within the patient).

Before these steps begin, a relative electron density volume is created using the CT image volume, CT-to-electron density data, and DICOM structure density override information (if applicable). This relative electron density volume is used in the three main steps detailed below.

# Fluence Calculation

The fluence calculation is responsible for simulating radiation transport within the linear accelerator treatment head. The inputs to the fluence calculation are a model of the linear accelerator head and the DICOM RT Plan. The outputs are fluence distributions for both the primary and extrafocal (i.e. scatter or secondary) sources. This dual-source model is depicted in Appendix Figure 1.



*Appendix Figure 1. Dual source fluence model*

Technical Highlights

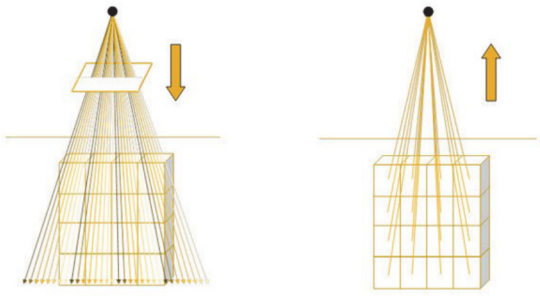
- Separate sources used to model primary, extra focal (scatter), and electron contamination radiation, each possessing their own weighting factor relative to the other components.
- The primary and extrafocal sources have their own spectrum and arbitrary radial intensity profile. The electron contamination source has its own spectrum.
- Accounts for transport though jaws and MLC completely, including aspects such as MLC tongue-and-groove thickness and MLC leaf end curvature.

# TERMA Calculation

The TERMA (or Total Energy Released per unit MAss) calculation describes radiation transport from the time it leaves the accelerator head to the time it first interacts within the patient. As the name indicates, TERMA describes the distribution of energy released within the patient.

Technical Highlights

- Inverse ray-tracing done to maximize GPU benefits (Appendix Figure 2)
- Exact radiological pathlength tracing (versus fixed step size)
- Pathlengths across 9 different material types are tracked during the ray trace process. These 9 values are subsequently combined with a 16-component energy spectrum to accurately characterize attenuation.
- Calculated every two degrees for VMAT



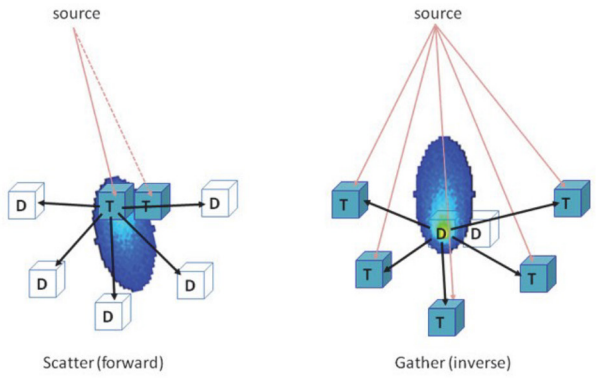
*Appendix Figure 2. Forward versus inverse TERMA calculation.*

# Superposition Calculation

Superposition accounts for radiation transport within the patient. When megavoltage x-rays interact in tissue, their energy is not deposited all at once; instead, the first interaction begins a shower of secondary photons, electrons, and positrons, which spread their energy throughout the patient volume. This energy spread is accounted for using dose spread arrays, also known as superposition kernels.

Technical Highlights

- Inverse superposition done to maximize GPU benefits (Appendix Figure 3)
- Collapsed Cone approximation with 90 anisotropic directions chosen to maximize forward-focused contributions to dose.
- Cumulative Cumulative Kernel (CCK) approach[1] used to minimize voxelization effects
- Kernel tilting and kernel hardening[2,3] over two energy bins used
- High resolution (1 mm, 1 degree) kernel
- Radiological Path Length indexing used to account for inhomogeneities
- Exact radiological pathlength tracing (versus fixed step size)
- Dose computed on a grid with 2.5 mm spacing (all dimensions)
- Calculation performed every five degrees for VMAT




*Appendix Figure 3. Forward versus inverse Superposition operation.*

# Appendix References

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