Benefits Analysis:
SunPoint™ Diode Detectors

SUN NUCLEAR corporation

SunPoint™

PRECISION QA

Pa PATIENT Ma MACHINE Rt ROUTINE Do DOSIMETRY

The Right Detector for the Right Application

Sun Nuclear manufactures products using diodes and ion chambers. Both offer unique advantages based on the application. Unlike some vendors who insist ion chambers are the only acceptable detector for every application, Sun Nuclear recognizes that diodes offer benefits that are in the best interest of the patient. For this important reason SunPoint Diode Detectors are selected as the dosimeter of choice for many Sun Nuclear products.

These benefits include:

1 ▶ Size.

SRS, IMRT, and VMAT deliver small beamlets to avoid critical structures and hit the target. When millimeters are so critical in the plan and delivery, they are also essential for measurement accuracy. Measuring only $0.64mm^2$ and $0.000019cm^3$, SunPoint Diode Detectors are smaller than ion chambers by orders of magnitude, which results in accurate dose plan QA measurements. Ion chambers may be a gold standard for dosimetry calibration; however this is not the case for patient QA. Ion chambers integrate over a much larger area resulting in a loss of accuracy known as Dose Volume Averaging. Dose Volume Averaging is characteristic in ion chambers for small field and gradient measurement; which is why Sun Nuclear only uses diodes for such applications.

2 ▶ Sensitivity.

The electron density of silicon is 18,000 times greater than air. Therefore a silicon diode can be thousands of times smaller than an ion chamber, while its sensitivity can still be 10 times higher. The measurement benefit of this is two-fold. First: a higher signal to noise ratio equals better measurement accuracy and reproducibility. Second: a smaller detector equals better measurement precision. Ion chambers must always be larger than diodes due to their low sensitivity and signal to noise ratio.

a Sensitivity as a function of accumulated dose.

SunPoint Diode Detectors exhibit consistent sensitivity with accumulated dose. Sensitivity variation is <0.5%/kGy at 6MV, <1.5%/kGy at 10 MeV. The benefit is infrequent array calibration (< once per year) even when detectors receive different accumulated doses.

b Sensitivity as a function of dose per pulse.

Unlike other diodes from different manufacturers, the SunPoint Diode Detector sensitivity only changes about ±1% for 600-fold changes in dose per pulse. Semiconductor diodes can remain linear with dose per pulse after very high accumulated dose. [2,5,6]

3 ▶ Stability.

SunPoint Diode Detectors have insignificant radiation degradation in short term and long term use. In a short term reproducibility test of 15 consecutive 60 MU measurements, response varied ±0.15%. Quantified over a 261 day period of use, MapCHECK (using SunPoint Diode Detectors) varied ± 0.2%. Both studies indicate SunPoint Diode Detector based arrays are more stable than ion chamber based arrays. [1,2,4,10]

4 ▶ Fast Setup.

SunPoint Diode Detector based instruments do not require warm-up or the application of bias voltage prior to use. Ion chamber arrays can require up to 60 minutes and 10Gy prior to use.[10,11] Warm-up is a result of the design of the instrument. Sun Nuclear's ion chamber based products do not require warm-up but do require bias voltage.

5 ▶ Calibration.

The calibration for SunPoint Diode Detector products is very stable. Users typically calibrate every one to three years using Sun Nuclear's patented 15 minute Wide Field Calibration[14] (WFC) method. WFC affords users an easy, accurate, and independent calibration method. WFC is used for ion chamber and diode array products and is a benefit to all Sun Nuclear array product users. Every Sun Nuclear array product receives a factory calibration using Sun Nuclear's in house linear accelerator or Cobalt 60 source. WFC provides the user the ability to calibrate their Sun Nuclear product with their own Linac, at any time they wish. This allows users to verify the calibration accuracy themselves, and to perform independent research. The accuracy of Sun Nuclear WFC has been clinically proven worldwide in thousands of cancer centers.

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6 Dependencies.

a Temperature.

Temperature dependence can be compensated by entering a temperature value, or more accurately by calibrating dose before measurement. The temperature coefficient of SunPoint Diode Detectors remains constant with accumulated dose. [7,9]

b Pressure.

Ion chamber response is dependent on temperature and pressure, while diode response is only dependent on temperature.

c Energy.

Energy dependence for SunPoint Diode Detectors is easily managed with calibration files. For example, 6MV will use a 6MV calibration file; 9MeV will use a 9MeV file.

d Field size.

Ion chambers have field size dependence for small and intensity modulated fields. SunPoint Diode Detectors can be used in all field sizes. The Sun Nuclear EDGE Detector, utilizing a single SunPoint Diode Detector, can be used to scan photon (MV) profiles up to 30 x 30cm, and percent depth dose up to 15 x 15cm. For array products using SunPoint Diode Detectors, such as MapCHECK, calibrate the array at the chosen depth if the field size is greater than 25 x 25 cm and deeper than 10 cm. [2]

e SSD and Depth.

SunPoint Diode Detector based arrays are proven to accurately measure dose at different SSD's and depths. MapCHECK IMRT QA depths range from 2-15cm and PROFILER 2 is used at varying depths as a substitute for water phantoms.[6]

7 n-type and p-type.

Diode performance depends on the individual detector, regardless of n-type or p-type. Several publications demonstrate that n-type diodes can perform better than p-type diodes. [2,5,7,8]

8 Absolute dose.

SunPoint Diode Detector based instruments measure the absolute dose accurately with the dose calibration of the reference detector to the standard accelerator output, exactly as an ion chamber device would do.

9 Lifetime.

High sensitivity and good stability give SunPoint Diode Detectors an extremely long life expectancy. The lifetime of Sun Nuclear instrument arrays (ion chamber or SunPoint Diode Detector based) are a result of changing practices and normal electronic and circuit obsolescence and failure. Life expectancy is at least ten years under normal use. After 100 kGy, SunPoint Diode Detector sensitivity is still much higher than that of an ion chamber.

Benefits of SunPoint Diode Detectors

- Smaller Active Area
- Better Sensitivity
- Thinner Active Thickness & Volume
- Less Drift
- No Dose Volume Averaging

Why chambers are wrong for IMRT, VMAT and stereotactic QA ►►►

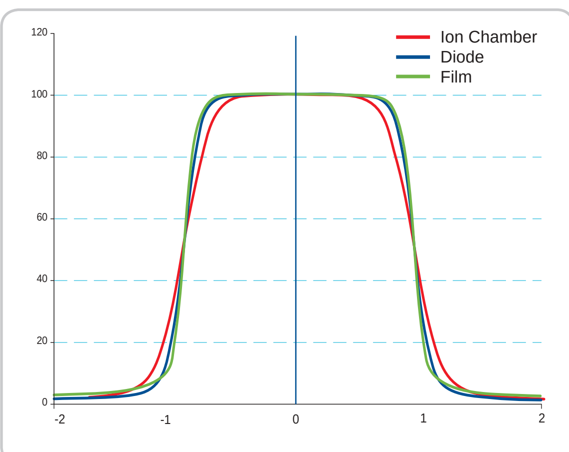
Sophisticated treatments such as VMAT, IMRT and SRS are collections of small beamlets with very steep dose gradients (penumbra) measuring 1 x 1cm^2 or smaller. Because these dose gradients are meant to tightly conform to patient anatomy and tumor volume, accurate and precise measurement of the dose gradients is of the highest importance.

Special care must be taken when comparing planned dose to measured dose. If the planned dose is modeled with an ion chamber, the dose gradients will be underestimated due to dose volume averaging. If QA is performed on the same beam with ionization chambers, gradients will continue to be underestimated, hiding a critical dose non-conformity error. When ion chambers are used for both beam modeling and QA, the planned dose and measured dose may agree because they BOTH under and/or over estimate dose to the target volume and surrounding structures. The QA results may be favorable, but they are not satisfying the objective of revealing inconsistencies between the conceptual planned dose and actual delivered dose.

Table 1: Comparison of penumbra width of a 2 x 2cm^2 field at 1.5cm depth for a 6MV beam[13]

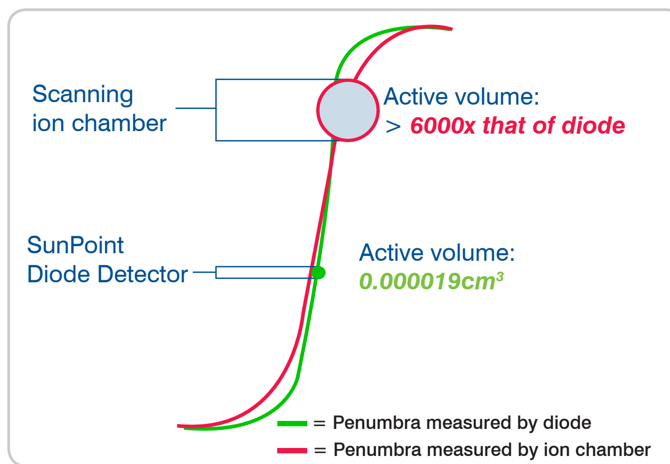
Manufacturer	Sun Nuclear	IBA	PTW	PTW
Detector	SunPoint	RK	PinPoint	0.125
Active detector size (mm)	0.8 x 0.8	4.0*	2.0*	5.5*
Measured penumbra width (mm)	2.9	4.6	4.1	5.3
Measured flatness (±%)	1.0	4.2	3.4	6.1

Figure 1



2 x 2cm field profile measurements with various detectors

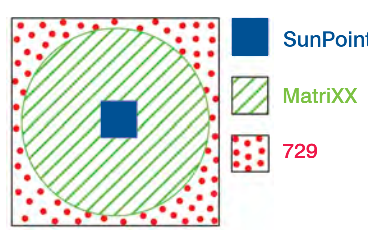
Figure 2



Small size = more precision, less averaging

Table 2: Comparison of active area, volume, and sensitivity[13]

		Manufacturer	Sun Nuclear	IBA	PTW
		Detector array	MapCHECK	MatriXX	729
Advantage	1	Active dimension (mm)	0.8 x 0.8	4.5*	5.0 x 5.0
		Active area (mm^2)	0.64	15.9	25.0
	2	Active thickness (mm^2)	0.03	5.9	5.0
		Active volume (cm^3)	0.000019	0.08	0.125
	3	Sensitivity (nC/Gy)	32.0	2.4	3.3



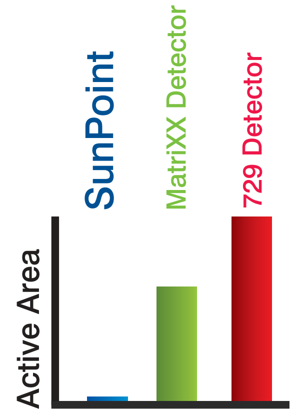
Relative scale size comparison of 2D array detectors.

*Diameter

Diode advantage 1: Smaller active area

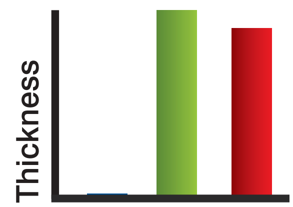
The SunPoint Diode Detectors used in Sun Nuclear products measure only 0.8 x 0.8mm ($0.64mm^2$). Table 1 clearly illustrates that both the 4mm RK chamber (similar in size to the MatriXX detector) and the 5.5mm 0.125 cc chamber (similar in size to the 729 detector) <u>significantly over estimate</u> the penumbra region by 1.7mm to 2.4mm (59% to 83%).

Penumbra over estimation is due to the large size of the chamber. As seen in Table 2, the active detection area of a SunPoint Diode Detector used in Sun Nuclear products is approximately $1/25^{th}$ the area of a MatriXX detector ($15.90mm^2$), and $1/39^{th}$ the area of a 729 detector ($25.00\ mm^2$).

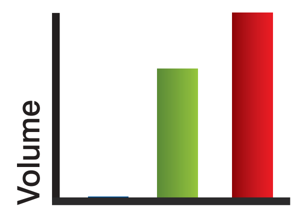


Diode advantage 2: Thinner active thickness and volume

The electrode spacing of the ion chambers in MatriXX and the 729 is more than <u>150 times larger</u> than the active thickness of the SunPoint Diode Detector. If the SSD is 100cm, there could be a 1% difference in beam intensity between the top and bottom of a 5mm thick chamber. The diode is taking a point measurement at exactly the specified depth, the ion chambers are taking an average measurement along a depth range.

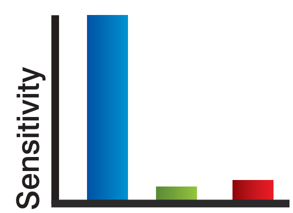


Additionally, the volume of the SunPoint Diode Detector is only $0.000019cm^3$. This is approximately 4,200 times smaller than a MatriXX chamber, and <u>6,500 times smaller</u> than a 729 chamber.



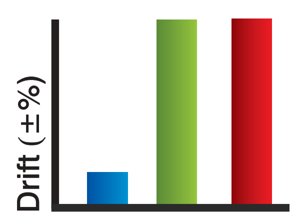
Diode advantage 3: Better sensitivity

A silicon pn junction diode is about <u>18,000 times more sensitive</u> than the air cavity ion chamber. The SunPoint Diode Detector has an active volume more than <u>4,200 times smaller</u> than the ion chambers used in MatriXX and 729, yet its overall sensitivity to radiation is still about <u>10 times higher.</u>



Diode Advantage #4 Less Drift

The diodes used in Sun Nuclear products have less drift than the detectors used in the MatriXX and 729. Users typically calibrate SunPoint Diode Detectors only once per year using Sun Nuclear's patented Wide Field Calibration[14]. The calibration takes only 15 minutes using the easy-to-follow steps in the SNC Patient software. See Case Study 2 for more details on drift.

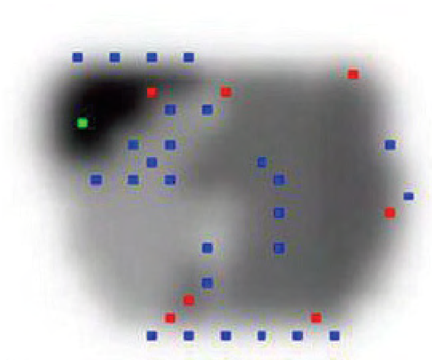


CASE STUDY 1: Dose modeling

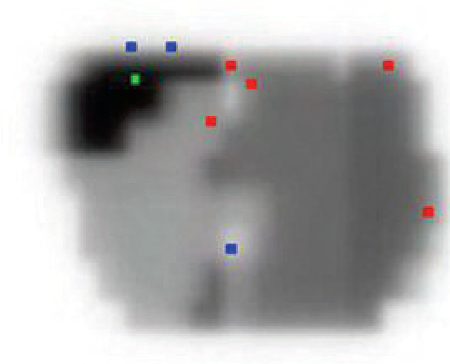
The errors in Figure 1 (a) are due to the fact that the radiation beam that was modeled was not reflective of the actual beam delivered to the MapCHECK. The beam model in (a) was based on scanning data from a large volume chamber. If a large chamber is used to collect the beam data for planning system beam modeling, the result will be planned dose maps that do not accurately portray the actual beam, and these inaccuracies will not be caught if the plan maps are also verified using large chambers.

Diode detectors are small enough to detect these dose volume averaging errors, as demonstrated in (a) below. After determining scenario (a) was unacceptable, this institution re-modeled their small fields with a 2mm detector, and when the beam was re-measured with the MapCHECK, dose map (b) resulted, and the pass rate rose from 79% to >95%. QA measurements with large chambers will not reveal these errors; in fact it may hide the error with an erroneously high pass rate, especially if the beam was modeled with a similarly large chamber.

Figure 3: IMRT plan errors detected by MapCHECK



(a) Original model 79% passed (6 mm detector)



(b) New model >95% passed (2 mm detector)

WARNING: *Ionization chambers have large measurement volumes and are NOT designed for accurate small field or steep dose gradient QA. Small beam models often model dose gradients and beam shape incorrectly. Attempting to discover such errors with ion chambers will extend the measurement error rather than reveal it.*

CASE STUDY 2: Reproducibility

In published reports, short term and long term SunPoint Diode Detectors reproducibility has been shown to be better than ion chamber arrays. Because ion chambers are typically desired for their stability, this is a significant finding and further strengthens the argument for using diode detectors.

Short Term Reproducibility		Long Term Reproducibility	
MapCHECK	± 0.15% (15 consecutive measurements)[1]	MapCHECK	± 0.20% (9 months totaling approximately 50Gy)[2]
MatriXX	Unknown. Requires 15 minute warmup[11]	MatriXX	± 1.30% (7 month period)[3]
729	± 0.50%[12]	729	± 1% (4 month period)[4]

FAQ #1: Do SunPoint Diode Detectors have a high instantaneous dose rate dependence?

No. SunPoint Diode Detectors exhibit a sensitivity variation of only ±1% over a 600-fold change in instantaneous dose rate (diode sensitivity change from 75cm to 250cm SSD in an open beam, and also underneath the primary collimator).

FAQ #2: Will I have to calibrate the diode array frequently?

No. Sun Nuclear uses proprietary radiation hardened diodes. Our diode sensitivity change is less than 0.5% / kGy with a 6 MV beam, and 1.5% / kGy with a 10 MeV beam. A Sun Nuclear user typically calibrates a diode array every 1 to 3 years for a typical patient load. The patented[14] array calibration procedure is easily performed in only 15 minutes by the user with a software wizard. There is NO need to send the unit back to the manufacturer for calibration. As seen in Case Study 2, ion chambers could have greater long-term drift than diodes. There are many factors that contribute to detector stability, such as material stability, electronic components, etc.

FAQ #3: Can SunPoint Diode Detectors measure in absolute dose?

Yes. By following a one-minute calibration routine in the SNC Patient software, the absolute dose calibration factor is obtained for the center diode. By multiplying this absolute dose calibration factor to the array calibration factor of each diode, SunPoint Diode Detectors can measure absolute dose.

FAQ #4: What is the lifetime of the SunPoint Diode Detectors?

SunPoint Diode Detectors has been in use since 2002 and prototypes are still in clinical use today. SunPoint Diode Detectors have a lifetime of more than 100 kGy, which for most centers will easily equate to more than 10 years.

FAQ #5: What happens if one of my diode detectors fail?

Diodes rarely fail. It is a misconception that diodes are more likely to fail than chambers. The diode detector is the simplest component on the detector array. If there is a failure, it is almost always a “channel measurement failure” and will most likely be in the measurement electronics, which are common to all array types, including ion chamber arrays. These electronic components are far more complex than a diode detector. Sun Nuclear includes a software feature to turn off a defective channel. This feature will not likely be used due to a defective diode, however it may be used if there is a channel measurement failure.

FAQ #6: Is a diode more likely to fail than an ion chamber?

No. A user is actually more likely to have an ion chamber failure because the leakage requirements are much more stringent for an ion chamber due to its much lower sensitivity and high voltage. Humidity and microscopic dust will have a much larger impact on ion chambers than on diodes.

FAQ #7: Is energy dependence an issue for SunPoint Diode Detectors?

No. With MV beams used in IMRT, the response change of the diodes with energy is negligible for the same energy beam. SunPoint Diode Detectors works perfectly if it is calibrated with each energy, taking only about 15 minutes.

FAQ #8: What impact will temperature have on SunPoint Diode Detectors?

Any changes in temperature in the measurement environment will not be important since the SunPoint Diode Detectors can be calibrated in absolute dose immediately before the measurement session.

FAQ #9: Will I get reproducible results with SunPoint Diode Detector based instruments?

Yes. Please see the case study on page 6.

Document references:

1 "Evaluation of a 2D diode array for IMRT quality assurance", D. Létourneau, et al, Radio. Oncol., 70(2), 199-206 2004 (2004).

2 "A 2-D diode array and analysis software for verification of intensity modulated radiation therapy delivery", P. A. Jursinic and B.E. Nelms, Med. Phys. 30, 870-879 (2003).

3 "Dosimetric characterization of a large area pixel-segmented ionization chamber", S. Amerio, et al, Med Phys, 31(2) 414-420 (2004).

4 "Characterization of a 2D ion chamber array for the verification of radiotherapy treatments", E. Spezi, et al, Phys. Med. Biol., 50, 3361-3373 (2005).

5 "Modeling the instantaneous dose rate dependence of radiation diode detectors", J. Shi, W.E. Simon, T.C. Zhu, Med. Phys. 30 (9), 2509-2519 (2003).

6 "Performance evaluation of a diode array for enhanced dynamic wedge dosimetry", T. C. Zhu et al, Med Phys 24, 1173-1180 (1997).

7 "Dose rate and SSD dependence of commercially available diode detectors", AJ S. Saini and T. C. Zhu, Med. Phys., 31 (4), 914-924 (2004).

8 "Diode in vivo Dosimetry for Patients Receiving External Beam Radiation Therapy", E. Yorke, et al, AAPM Report No. 87 (TG62), Medical Physics Publishing, College Park, MD, 2005.

9 "Accuracy contra work load in In Vivo Dosimetry", G. Rikner and E. Grusell, Dept of Med Phys, Uni Hosp, Uppsala, Sweden, www.scanditronix-wellhofer.com.

10 "Comparison of two commercial detector arrays for IMRT quality assurance", Jonathan G. Li,Guanghua Yan,and Chihray Liu, JACMP, Volume 10, Number 2, Spring 2009

11 I'mRT MatriXX User Manual

12 User Manual 2D Array Seven29 (T10024) Version 1.1

13 Data provided by Ron Watts, Ph.D.

14 US Patent No. 6,125,335

Clinical testimony ▶▶▶

"For domestic plan verification, the expected two-dimensional distribution of the array signals is calculated via convolution of the planned dose distribution, obtained from the treatment planning system, with two-dimensional response function of a single chamber."

B. Poppe et al, referring to PTW 2D chamber arrays
"Two dimensional ionization chamber arrays for IMRT plan verification"
Medical Physics, April 2006, Vol. 33

(a 4mm chamber)..."is small enough to accurately measure the profile, as long as the field size is not smaller than 4x4cm^2"

S. Amerio et al, original collaborators to the MatriXX
"Dosimetric characterization of a larger area pixel-segmented ionization chamber"
Medical Physics, February, 2004, Vol. 31

SunPoint Diode Detectors ▶▶▶ The Right Detector for the Right Application

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