Toward in vivo dosimetry with plastic scintillation detectors

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Disclosure

- I own patents on scintillation dosimetry that have been licensed to Standard Imaging and Medscint
- I have ongoing research funding in partnership with Medscint

CIRMS 2026 — Need

Annual Meeting · April 13–15, 2026

Progress in **In vivo dosimetry** is currently blocked because we lack **Unobtrusive online dosimeters with uniform response**, which prevents **Monitoring dose delivery to critical structures**.

Objectives

1. Present the principles of plastic scintillation detectors (PSD)
2. Summarize strengths and weaknesses of PSD for *in vivo* dosimetry
3. Discuss the current state of commercial PSD
4. Show examples of PSD usage for *in vivo* dosimetry

A brief introduction to scintillation dosimetry

Plastic scintillators

- Plastic scintillators are materials that emit visible light when irradiated
- The amount of light produced within a scintillator is related to the absorbed dose
  - Light yield, L: number of scintillation photons, N emitted per energy absorbed, ε:

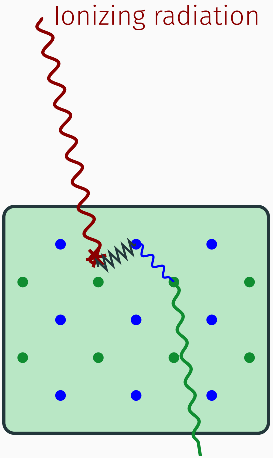
$$L = \frac{\mathrm{d}N}{\mathrm{d}\varepsilon}$$

⇒ Dosimetry is performed by collecting and quantifying the scintillation light

source: Plastic scintillatorsm chemistry and applications, 2021

The scintillation process

- A polymer matrix doped with fluorophores
- The scintillation process:
  1. Radiation dose deposition in the polymer matrix
  2. Non-radiative transfer to a primary fluorophore
     - Through dipole-dipole interaction
  3. Radiative transfer to a secondary fluorophore (wavelength shifter)
  4. Emission of visible light
     - Broad emission spectrum



Scintillation → dose

- The amount of scintillation light, N, can be expressed in term of absorbed dose

$$N = L\rho\overline{D}_{\mathrm{scint}}V_{\mathrm{scint}}$$

L: Light yield
ρ: Scintillator's mass density
$\overline{D}_{\mathrm{scint}}$: Average dose in scintillator
V_{scint}: Scintillator's volume

$$\Rightarrow \boxed{\overline{D}_{\mathrm{scint}} = \frac{N}{L\rho V_{\mathrm{scint}}}}$$

source: Plastic scintillatorsm chemistry and applications, 2021

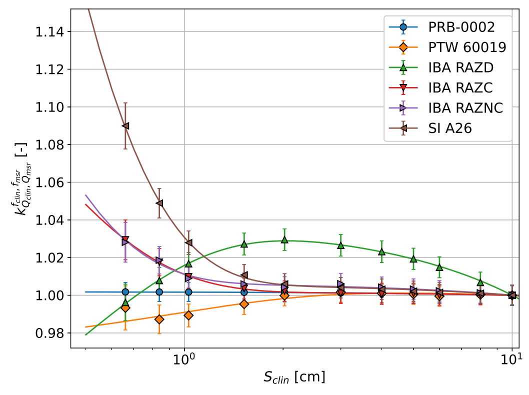
Scintillation → dose: effect of high LET

- At high LET, ionization quenching cause a non-linearity in the scintillation-to-dose relationship
    - High LET causes lower scintillation emission per unit dose
    - ⇒ L becomes a function of the ionizing radiation stopping power, $L(S/\rho)$
- Recent work[1] has shown that quenching can cause field size dependence even at megavoltage photon energies
    - Because of the varying contribution of lower energy scatter radiation
    - Small but measurable effect: 0.6% between 0.5×0.5 cm^2 and 10×10 cm^2

[1] Santurio and Andersen 2019.

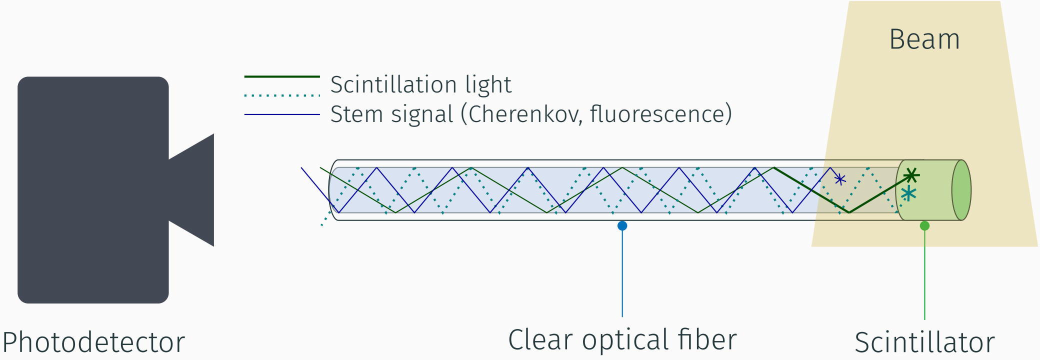
Scintillation → dose: effect of high LET

- Medscint designed the PRB-0002 to balance quenching with material response[2]
- Uniform response for a large range of field sizes
  - $k^{f_{\mathrm{clin}},f_{\mathrm{msr}}}_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}} \simeq 1$



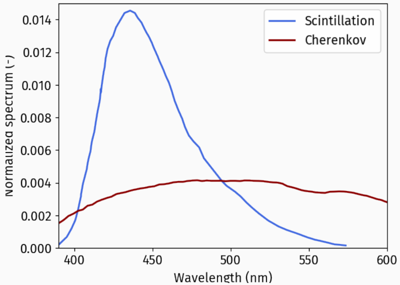
[2]Gingras et al. 2025.

Anatomy of a scintillation dose detector



Signal of interest

- The signal of interest is the scintillation
- However, it overlaps with contamination (stem) signals
  - Cherenkov light, fluorescence
- The scintillation must be decoupled from the contamination



Scintillation signal decoupling strategies

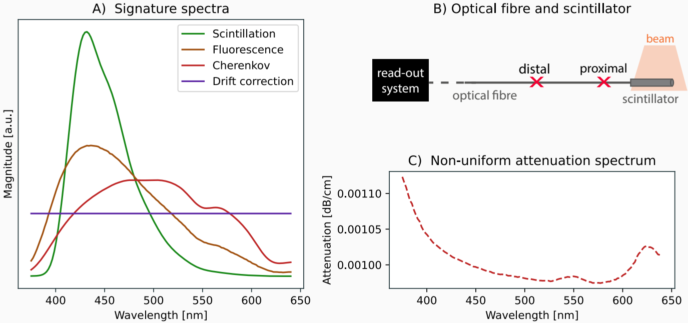
BluePhysics

1. Background subtraction with a *blank* optical fiber
   + Simple calibration procedure
   - Require that both the scintillator and the background fiber receive the exact same dose
2. Two-wavebands spectral decoupling → STANDARD IMAGING
   + Use only a single optical fiber and 2 channel electrometer
   - Can only account for the superposition of 2 spectra
3. Hyperspectral unmixing
   + More powerful decoupling (can account for any number of spectral overlap)
   - Complex calibration procedure

medscint

Scintillation signal decoupling strategies

- Hyperspectral unmixing can account for individual stem components
- It can also partially correct spectral attenuation in the optical fiber

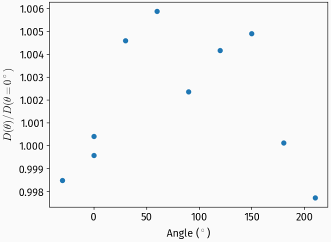


L DeVries et al. *in revision*

Scintillation for *in vivo* dosimetry

General properties of plastic scintillators[3]

- Electron density and atomic composition close to water
- S/ρ and μ_{en}/ρ within $\sim$2% of water
- Perturbation factor (P_{scint}) close to unity



Most vendors offers options with at least 0.5 mm resolution

- High spatial resolution
- Fast emission

Emission in < 10 ns
Limited by the photodetector

- Water equivalent
- Good angular response
- Independent of:
  - Dose rate
  - Pressure
- MR compatible
- Reusable

[3] See, for example: *Scintillation Dosimetry*. CRC Press, 2018

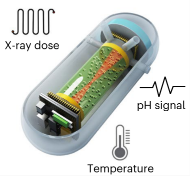
For *in vivo*

In the context for *in vivo* dosimetry, plastic scintillators offer:

- A uniform, accurate response for a large range of irradiation conditions
  - Treatment can include large and small fields
  - Work for any beam orientation
    - Ideal for VMAT
- No significant beam Perturbation
  - *e.g.* A 0.5 mm thick probe will cause an attenuation of $\sim$0.5 mm of water
  - Not an important cause of backscatter
- Online readout

Potential limitations for *in vivo* applications

- Scintillators exhibit a small temperature dependence
  - 0.18%/°C reported[4] for Exradin W2 between 18 and 39°
  - Can be insulated when using 'on' a patient
  - Otherwise, calibration at a specific temperature can be done
- Require a cable for readout
  - Future scintillation dosimeters *could* be wireless[5]



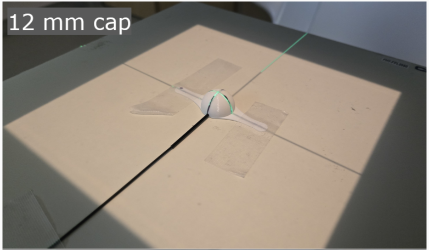
[4] Jacqmin et al. 2022.
[5] Hou et al. 2023.

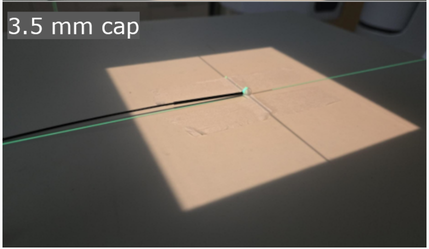
In vivo in practice

- Dose to the skin
  - In the buildup region → challenging to measure
  - Challenging for the TPS
  - **Goal**: validate TPS accuracy
- Out of field dose
  - Low doses
  - Challenging for the TPS
  - **Goal**: validate TPS accuracy + field position
- Dose in depth
  - Not usually possible to measure *inside* a patient
  - Accurate TPS calculation
  - **Goal**: validate treatment field position

Buildup caps

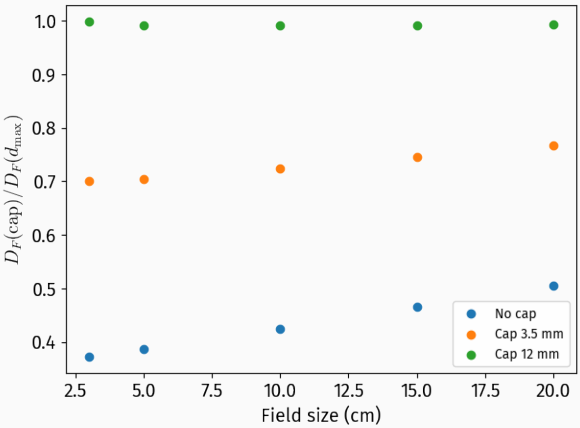
- Buildup caps → measure at $\sim d_{\mathrm{max}}$
- Too small:
  - Field size dependence due to lack of scatter
- Too large:
  - Unecessary field attenuation
  - Increase skin dose





Buildup caps

Field size dependence



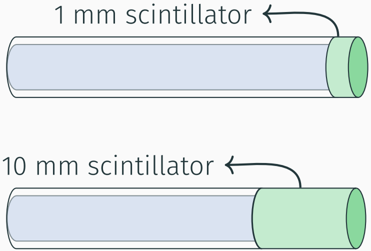
Perturbation at d_{max} at 0° incidence

Field size (cm^2)	Cap size 3.5 mm	Cap size 12 mm
3×3	1.0 %	2.8 %
10×10	1.1 %	3.1 %
20×20	1.1 %	3.6 %

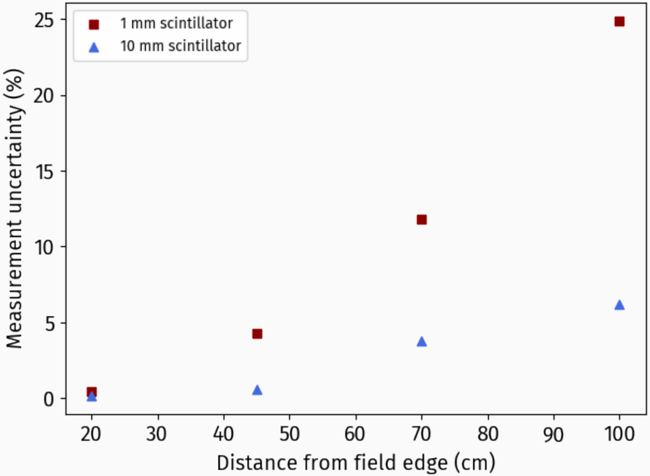
Time for temperature equilibrium:
$\sim$ 2 min

Out-of-field measurements

- Out-of-field:
  - Dose ↓
  - Measurement noise ↑
- **Solution**: larger probes
  - Increase signal → noise ↓
  - However: spatial resolution ↓



Out-of-field measurements

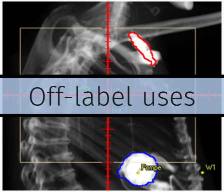


In vivo applications of scintillation dosimetry

Examples of *in vivo* applications

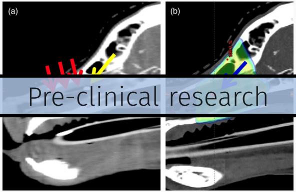
Despite no FDA-approved *in vivo* PSD, some applications have been reported

1



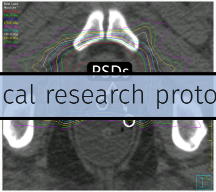
Off-label uses

2



Pre-clinical research

3



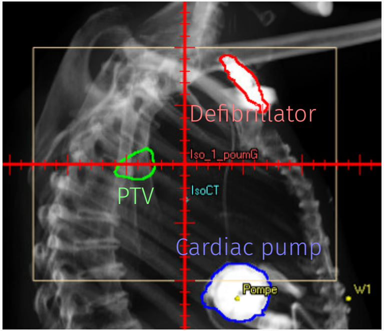
Clinical research protocols

(1) Monitoring of cardiac Implantable Electronic Devices (CIED)

- Occasional (1-4 patients/yr)
  - CIED close to the field, rare cases
- Dosimeter: Exradin W1
- Measurements close to CIED
  - Under lead shield, if one is used
- 1-9 measurements per patient
  - One per fraction
  - One per PTV dose level
- Data per beam angle or arc

'*rare*' cases are increasingly seen!

Rare case: cardiac pump + defibrillator



Dose	Estimated	Measured
Arc 1	-	9.6 cGy
Arc 2	-	14.1 cGy
Total	48cGy	23.7 cGy

(1) Monitoring of Total Body Irradiation (TBI)[6]

- TBI: non-standard conditions and/or multiple junction fields
  $\Rightarrow$ Good cases for in vivo monitoring with PSD
- Validation of non-TBI irradiations on simple solid water phantom:

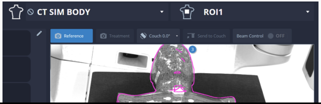
Plan type	**Fields**	**TPS dose** (cGy)	**Measured dose** (cGy)	**Difference** (%)
Head	6 Dynamic	179.0	177.7	-0.7
Thorax	VMAT	174.6	174.7	0.1
Abdomen	VMAT	214.6	212.5	-0.9
Pelvis	VMAT	197.3	191.2	-3.1

[6] Chris Jonhstone, BC Cancer, *unpublished*

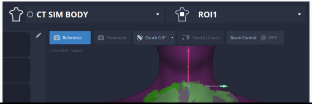
(1) Monitoring of Total Body Irradiation (TBI)[7]

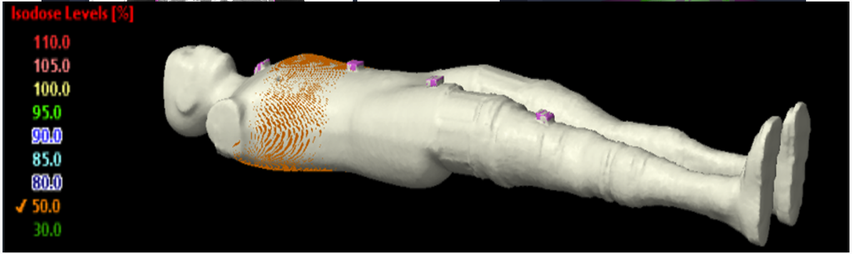
Using Surface guidance for detector positioning

align the patient



align the PSD + bolus





[7] Chris Jonhstone, BC Cancer, *unpublished*

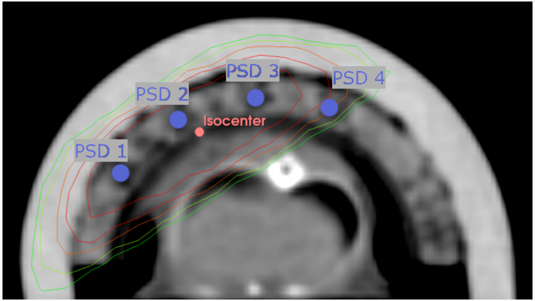
(1) Monitoring of Total Body Irradiation (TBI)[8]

Junction area	Fields	TPS (cGy)	PSD (cGy)	Δ (%)	Setup
Head	6 VMAT + Dynamic	178.5	184.9	3.6	AlignRT
Thorax	VMAT	239.8	245.1	2.2	AlignRT
Pelvis	VMAT	119.6	111.0	-7.2	Ruler
Legs	Dynamic	254.0	231.9	-9.8	Ruler

[8] Preliminary results, Chris Jonhstone, BC Cancer, *unpublished*

(2) Murine model for skin healing

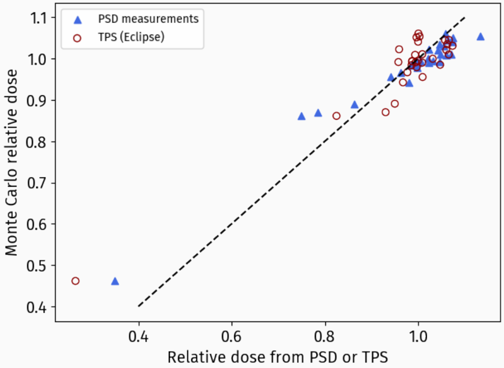
- Study on skin damage and healing
  - 20+ mice irradiated
  - 45 Gy at isocenter
  - Parallel-opposed tangential fields
- Measurements performed an array of 4 PSD from Medscint
  - Detectors placed close the the high dose region



(2) Murine model for skin healing

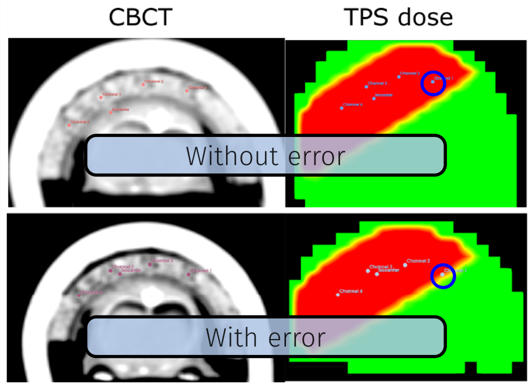
Relative agreement with Monte Carlo

Measurements	3.8%
TPS (Eclipse)	4.5%

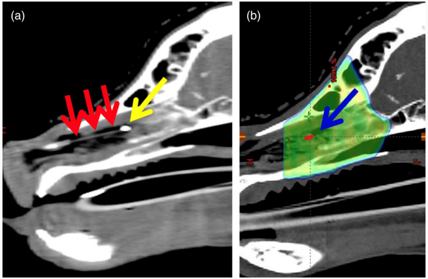


(2) Murine model for skin healing

- In vivo dosimetry catches errors!
  1. Forgot to adjust table height: all detectors out of field
  2. Small position error: one detector on field edge
     - Expected 39.2 Gy with PSD 1
     - Measured 15.0 Gy!



(2) Dog model[9]

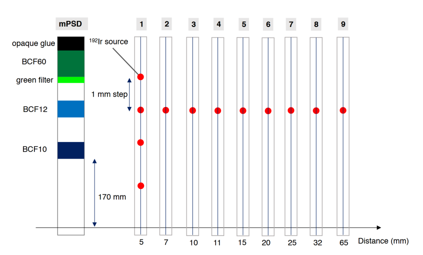


- Study by Schoepper et al.
- VMAT and IMRT treatments
- Intracavitary dose measurements with Medscint's RP100
- Include correction for temperature
  - 1.7% - 1.9%
- Measurements: 98.3%-103.2%
- Largest differences seen at low dose rates (< 100 MU/min)

[9] Schoepper et al. 2022.

(3) Brachytherapy source tracking[10]

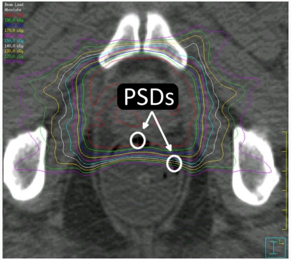
- In vivo measurements are well suited for brachytherapy
- Multi-point scintillation detectors are possible with an hyperspectral calibration approach
  - ⇒ Can have mulitple measurement points in a single cathether
  - ⇒ With multiple points: HDR source position can be triangulated

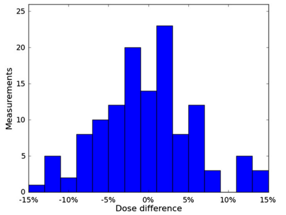


[10] Linares Rosales et al. 2020.

(3) Rectal wall monitoring[11]

- 2 PSDs mounted on a rectal balloon
- 5 patients, measured twice weekly
- 1 reading per detector every 10 s
- Detectors located close to strong dose gradients
- Overall precision estimated between 5.6% and 7.1%





[11] Wootton et al. 2014.

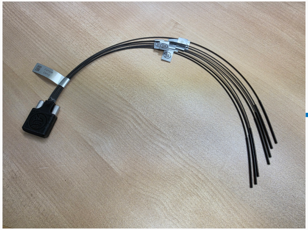
Conclusion

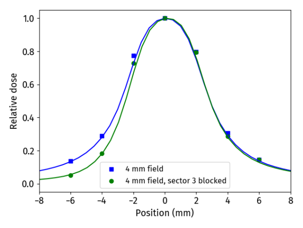
Plastic scintillation dosimeters

- Despite no commercial detectors approved for *In vivo* dosimetry, PSDs have a great potential
    - Uniform response, accurate, radiotransparent
- Several cases of PSD for *in vivo* dosimetry have been reported in the literature
- Limitations are few
    - Small temperature dependence, not (yet) wireless

The (near) future

PSD arrays will provide high accuracy for the most complex cases

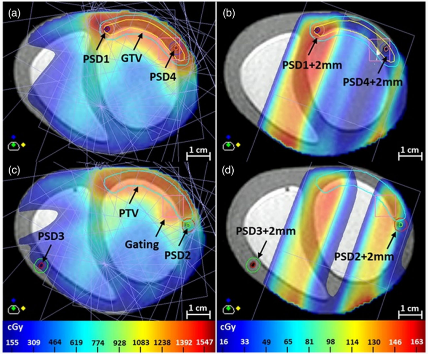




Measurements of 4 mm Gamma Knife fields

The (near) future

PSD will offers online feedback on fast treatments[12]



- A 5-PSD array integrated in a deformable cardiac phantom
- Fast readout: 14.7 Hz

[12] Aubert et al. 2026.

References

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