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How lack of in vivo dosimetry decreases safety and efficiency in brachytherapy

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Disclosure

Patent for RADPOS Dosimetry System

A. Saoudi, J.E. Cygler, R.W. Ashton, US Patent 7831016

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Objectives

- To present rationale for in vivo dosimetry in brachytherapy
  - increased safety
  - efficiency
- To discuss challenges in clinical implementation of in vivo dosimetry program
- To review currently available commercial systems for on-line in vivo dose measurements

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Rationale for in vivo dosimetry in brachytherapy

"To err is human" – *Alexander Pope, An Essay on Criticism, Part II* , 1711

- Errors and dose misadministrations in radiotherapy can result in:
  - Underdosing (geographic miss) of the tumor
  - Overdosing of healthy organs
- Magnitude of errors range
  - from a few percent to lethal doses
  - from a couple of millimeters to complete misses of the tumor
- Many brachytherapy procedures are performed without the safeguards of Record and Verify systems
- In vivo dosimetry is the only way to know what dose was actually delivered to the tumour and organs at risk, OAR

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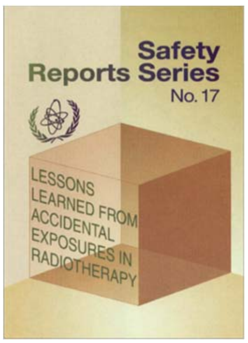
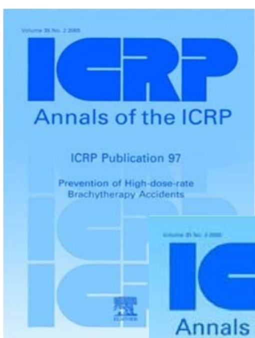


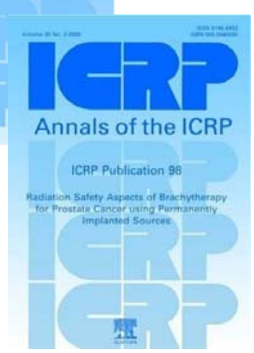
Safety Reports Series No. 17 (2000)

30% of cases are incidents in brachytherapy



ICRP Publication 97 (2005)

Prevention of High-Dose-Rate Brachytherapy Accidents



ICRP Publication 98 (2005)

Radiation Safety Aspects of Brachytherapy for Prostate Cancer using Permanently Implanted Sources

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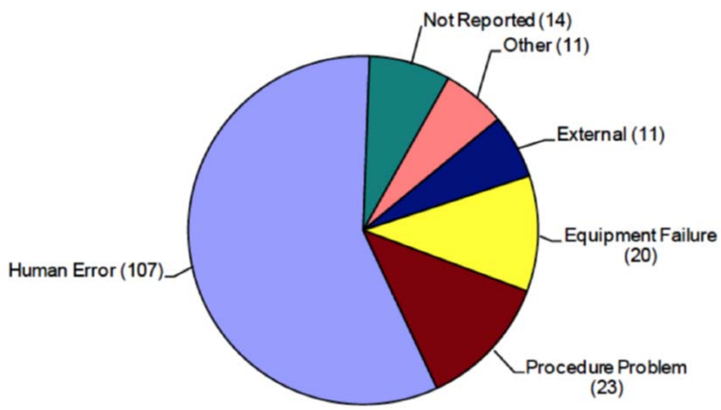
Types of errors in brachytherapy

- Equipment errors
  - mechanical errors
  - control unit failure
  - computer
  - source cable
  - applicators
- Procedure problems
- Human errors



U.S. NRC NUREG-2170 (2017)

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Examples of incidents in HDR brachytherapy related to human errors

- Human errors
  - treatments given to wrong patients
  - incorrectly prescribed / delivered doses or repeated treatments to the same patient.
  - Treatments given to a wrong site (e.g. *wrong orifice treated)*
  - Errors during treatment planning (e.g. r*everse order of entry of dwell positions; applicator diameter confused with radius; wrong dwell steps; wrong catheter length***)**

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Causes of human errors

- Complex, high pressure work environment in brachytherapy
- Combined with how the human brain works

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Prospective Memory

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Prospective Memory

- Prospective memory involves remembering to perform an action at the appropriate time (*McDaniel & Einstein, 2000*).

- Depends on:
  - How the human brain works
  - Complexity of work environment

- Brachytherapy setting
  - requires multi-tasking
  - frequent interruptions and distractions

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Prospective Memory - vulnerability

- Brachytherapy workers carry a particularly high load on their prospective memory
  - risk of errors

- ***Eliminating or minimizing the interruptions during procedures could help to reduce load on prospective memory and therefore human errors.***

- ***In some cases, in vivo dosimetry would have prevented propagation of certain errors to multiple fractions/patients and therefore improve safety and efficiency in brachytherapy.***

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Recent (2018) incident in North America: impact on safety and efficiency of brachytherapy process

- HDR cervix treatments
  - wrong catheter LENGTH
    - geographic miss of the tumor
    - overdose of healthy tissues

- Investigation
  - 25 patients possibly affected over a period of time
  - patients informed

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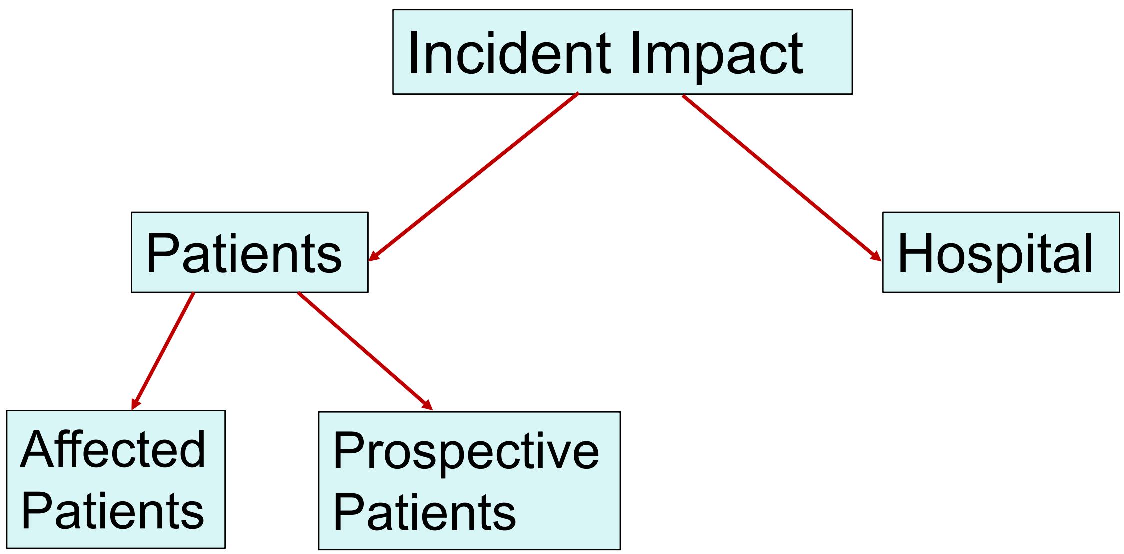
Negative impact of error on safety and efficiency:



Impact on safety and efficiency: Affected Patients

- Impact on affected patients – Quality of Life
  - Treatment compromised
    - Failure of tumor control?
    - Overdosed OAR complications?
  - Additional close follow-ups of identified patients
  - Additional diagnostic and pathological tests ordered on periodical basis
  - Emotional impact - anxiety and anger

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Impact on safety and efficiency: Prospective Patients

- Impact on prospective new cervix patients – Quality of Life
- HDR treatments of future cervix cancer patients suspended till further notice
  - Prospective patients had to travel to other centres
    - Extra cost and inconvenience for these patients

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Impact on safety and efficiency: Cancer Centre

Impact on cancer centre

- Extra workload and related cost
  - Close follow-ups of identified patients
  - Additional diagnostic and pathological tests ordered for affected patients on periodical basis

- Suspension of HDR treatments of cervix cancer till further notice
  - Loss of funding for the involved centre

- Reputation

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Conclusions / lessons learned

There are many lessons learned, but in the context of this lecture:

Routine, adequate in vivo dosimetry would

- ***limit the number of patients / tx fractions affected by this error***
- ***Improve safety and efficiency in brachytherapy***

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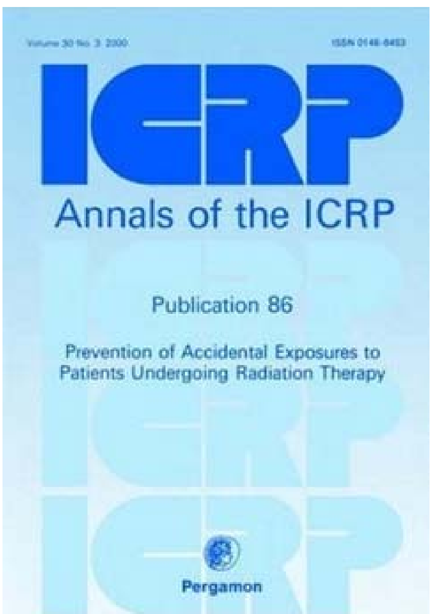

ICRP 86 (2000) – “adequate in vivo dosimetry would prevent most of accidental exposures”

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What does "adequate" mean?

- Every fraction?
- Once a week?
- First fraction only?

We need to define what "adequate" means!

ESTRO's basic philosophy includes routine in-vivo dosimetry as an important part in Quality Control of radiotherapy

In vivo dosimetry is required by law in some countries

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Routine in vivo dosimetry program in brachytherapy

What is needed ?

- Robust dosimetry system
  - small detectors with high S/N ratio
  - minimally intrusive to the patient
  - fast and reliable, real-time dose readout

Types of detectors used for in vivo dosimetry

- TLD
- OSL

off-line (passive) dosimetry

- Diodes
- MOSFETs
- PSD
- RL

on-line (real-time) dosimetry

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Diode system

- Measures rectum and bladder dose
- A five-diode rectum probe
- Two types of single bladder probes

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Advantages and disadvantages of diodes

Advantages

- High sensitivity(18000× equal volume ion chamber)
- Real time on-line readings
- Efficient (fast) in use
- Waterproof
- Durable

Disadvantages

- Temperature dependence
- Energy dependence
- Angular dependence
- Different detectors for photon and electron beams
- Radiation damage – change of sensitivity with accumulated dose
- Cumbersome cables on most systems

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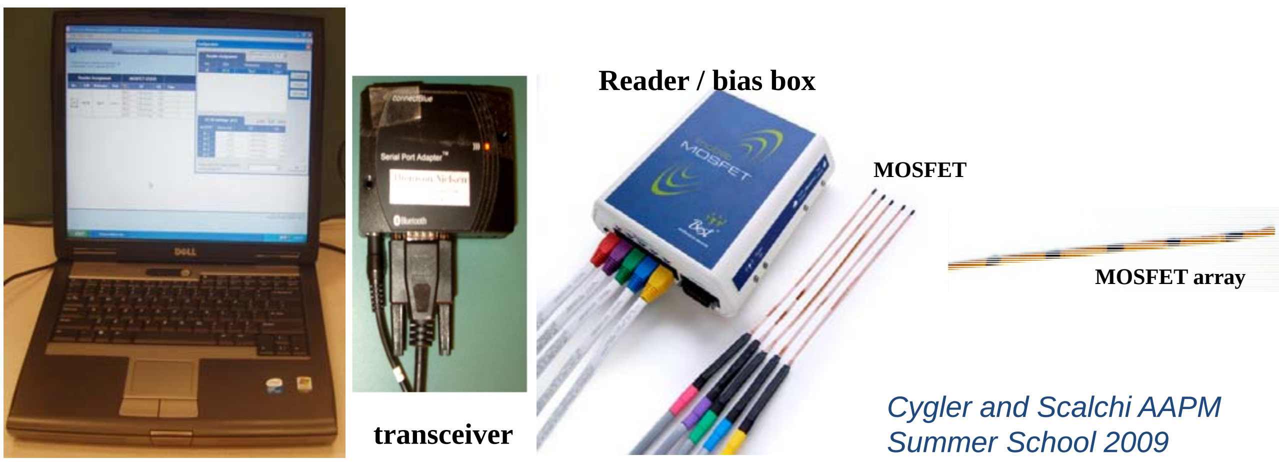
Mobile MOSFET system



Cygler and Scalchi AAPM Summer School 2009

Two physical detector sizes:

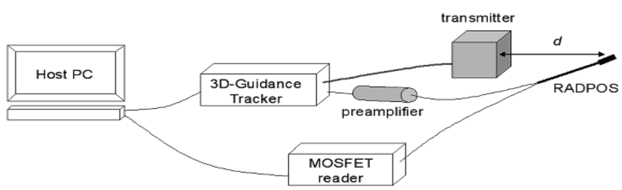
- standard (8 x 2.5 x 1.3 mm^3)
- microMOSFETs (3.5 x 1 x 1 mm^3)
  - Suitable for brachytherapy

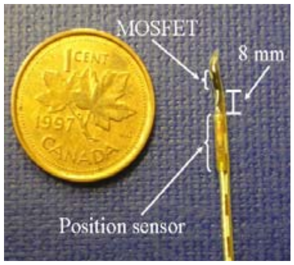
Two detector active volumes (sensitivities):

- Standard (0.2 x 0.2 x $5 \cdot 10^{-4}$ mm^3)
- High (0.2 x 0.2 x $1 \cdot 10^{-3}$ mm^3)

RADPOS*
Time-resolved dosimetry system

- Combination of microMOSFET dosimeter and electromagnetic positioning sensor
- Simultaneous measurements of dose and spatial position
- Software allows sampling dose and position manually/automatically
- Real-time treatment verification tool
  - Patient and/or organ motion
  - Accuracy of delivered dose
- Suitable for brachytherapy





*RADPOS, A. Saoudi, J.E. Cygler, R.W. Ashton, US Patent 7831016;
Cherpak et al, Med. Phys. 2009, Med Phys 2011, Radiother. Oncol. 2012

Advantages and disadvantages of MOSFET detectors

Advantages

- Instantaneous readouts (on-line dosimetry)
- Very small active volume
- dual detectors eliminate most correction factors
- No temperature dependence for dual-MOSFET-dual-bias
- Waterproof
- Efficient in use (doesn't consume much time)

Disadvantages

- Finite life expectancy
- Energy dependence
- Some (2.5%) angular dependence
- Temperature dependence for single- MOSFET- single-bias detector

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Exradin W1 Plastic Scintillator

Plastic Scintillator Detector, PSD

Physical probe size is 2.8 mm diameter, 42 mm length

Active volume size is 1.0 mm diameter, x 3.0 mm length

http://www.standardimaging.com/exradin/exradin-scintillator/

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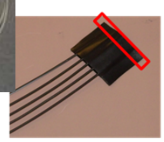
In vivo dosimetry with PSD

- Small size (2.8 mm diameter x 42 mm long)
  - can fit into rectal probe
  - can fit into Foley catheter

Exradin W1 Scintillator
from Standard Imaging



A detector patch

- The red line represents the dose sensitive region
- Detector elements are spaced every 2 mm

The detectors are mounted on a rectal balloon

Pictures courtesy of S. Beddar

Archambault L, et al, Int J Radiat Oncol Biol Phys 78:280-287, 2010.

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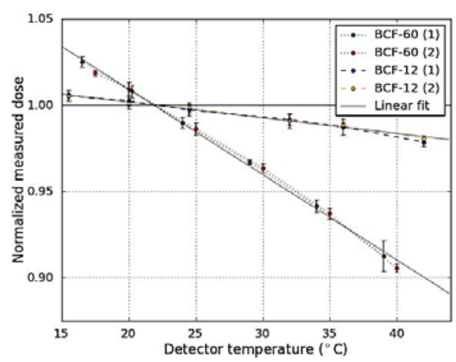
Advantages and disadvantages of plastic scintillators

Advantages

- On-line system
- Spatial resolution
- Linear response to dose
- Dose rate independence
- Energy independence
- Easy to produce
- Relatively inexpensive

Disadvantages

- Some temperature dependence
- Some radiation damage (~ 2% / kGy)



Wootton and Beddar, PMB 2013

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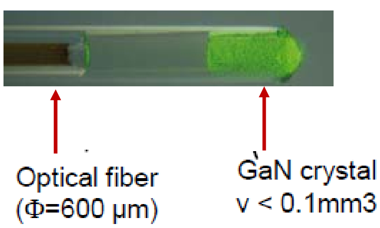
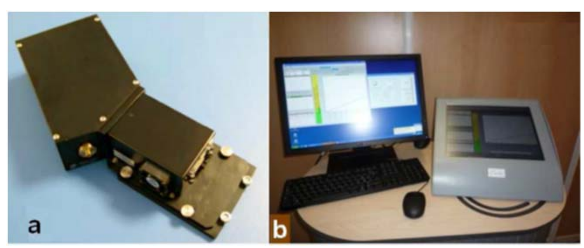
In vivo dosimetry with RL detectors: Securidose -BT

- Based on GaN crystal radioluminescence
- Real-time dosimetry system for HDR
- Developed by the universities of Grenoble (UJF) and Lyon (UCBL) and Dosilab Co
- Miniature crystal fits in a brachytherapy needle





https://www.dosilab.ch/en-ch/home

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Technical challenges for in vivo dosimetry in brachytherapy

- High dose gradients
- Short treatment distances

} large effect of positioning errors

- Energy dependence of detector response
- Uncertainties on radiation source parameters
- Shortcomings of dose calculation algorithms

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Barriers to routine in vivo dosimetry

- Cost (?)
  - Equipment – lack of fully integrated systems (?)
  - Staff to perform and analyze measurements
- Efficiency - increased treatment and staff time (?)

Not true for fully integrated system

- Staff resistance (?)
  - Lack of well documented guidelines, protocols and procedures (?)
  - Lack of proper training
  - Extra work load
  - Uncertainty about possibly changing work role in the treatment team

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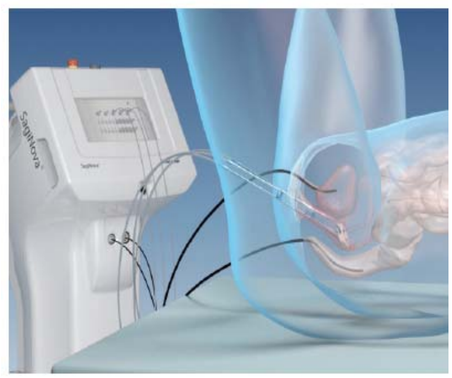
Integrated in vivo dosimetry - SagiNova®

Eases handling of real-time in vivo dosimetry

- Integration of probe connection into treatment delivery unit
- Integrated live monitoring of doses to rectum and bladder at the control console
- Complete data integrated in treatment report
- Warnings displayed if dose limits are exceeded
- Individual definition of dose limits for bladder and rectum



Dosimetry equipment of PTW

http://www.bebig.com/united_states/products/hdr_brachytherapy/new_saginova/

Eckert & Ziegler BEBIG – SagiNova® Presentation 2016

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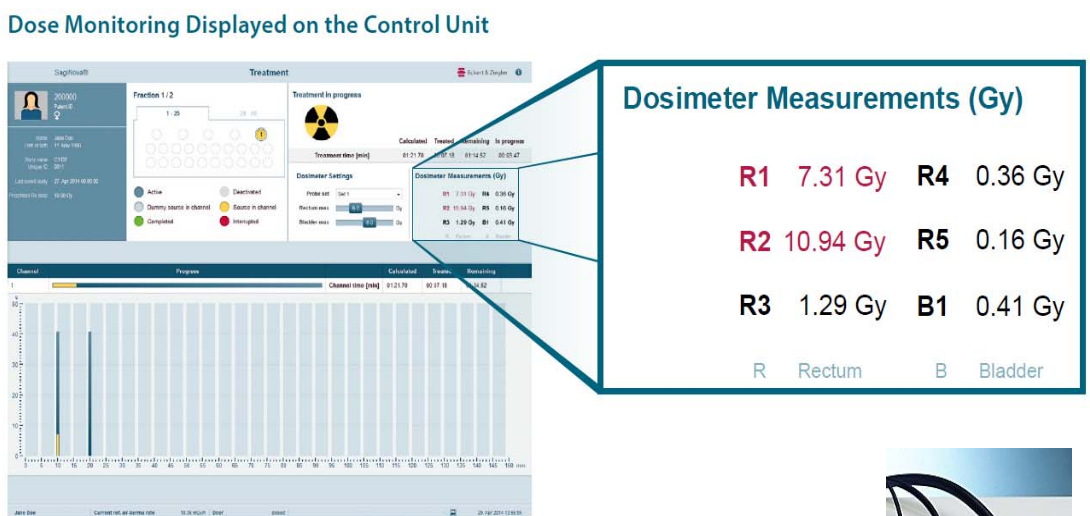
Integrated in vivo dosimetry

http://www.bebig.com/united_states/products/hdr_brachytherapy/new_saginova/

Live monitoring of dose to rectum and bladder including highlighting of high values



Diodes for dose measurement in bladder and rectum

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Eckert & Ziegler BEBIG – SagiNova® Presentation 2016

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Conclusions

- Errors in brachytherapy dose delivery do happen
- Human errors account for the largest fraction of all errors
- They can affect multiple tx fractions and/or patients
- Errors have negative impact on safety and efficiency of the brachytherapy process
  - result in compromised treatment outcomes
  - consume extra time and resources
- Routine in-vivo dosimetry would prevent propagation of errors to multiple tx fractions and/or patients and therefore improve safety and efficiency in brachytherapy
- Commercial in vivo dosimetry systems exist and should be routinely used in brachytherapy

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On-line measurements on patients

- Waldhäusl et al, *Radiother.and Onc.* (2005), **77,** 310 (diodes, 55 patients)
- Cygler et al, *Radiother. and Onc.* (2006), **80,** 296 (single MOSFET, 5 patients)
- Nose et al, *Int. J. Rad. Onc. Biol. Phys*. (2008), **70**, 626 (RPLGD, 66 patients) *
- Andersen et al, *Med. Phys*. (2009), **36**, 5033 (RL, 5 patients)
- Bloemen-van Gurp et al, *Int. J. Rad. Onc. Biol. Phys*. (2009) **75**,1266 (MOSFET array, 5 patients)
- Suchowerska et al, *Int. J. Rad. Onc. Biol. Phys*. (2011) **79**, 609 (PSD, 24 patients)
- Cherpak et al, Brachytherapy, **13**, (2014)169 (RADPOS, 16 patients)
- Carrara et al, *Radiother.and Onc* . (2016) **118** 148 (MOSkins,12 patients)

passive (not on-line) detectors

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Thank you