General characteristics of radiation dosimeters and a terminology to describe them

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Basic quantities and notation: detector reading

Detector reading: quantified output of detector corrected to standard reference conditions

- -meter reading
- -charge reading
- -current reading
- -light output
- -ESR signal peak-to-peak

$$M_{\mathrm{det}}(D, \dot{D}, Q, \theta, \phi)$$

$$M_{\mathrm{det}}^{\mathrm{raw}}(D, \dot{D}, Q, \theta, \phi, T, P, H)$$

May need correction for T, P, H, polarity effects or ion recombination etc

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Basic quantities and notation: dose to the detector

$$D_{\mathrm{det}}(D, \dot{D}, Q, \theta, \phi)$$

Average absorbed dose to material of detector

-related to active material of detector system

For ion chamber -dose to gas in cavity.

For diode detector -dose to active region of silicon wafer.

Can have same dependencies as M_{det}

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Basic quantities and notation: dose or kerma to medium

$$D_{\mathrm{med}}(Q) \qquad K_{\mathrm{med}}(Q)$$

-quantities at point of measurement in medium med in absence of detector

-usually the quantity of interest

-can depend on many influence quantities (e.g. depth, beam quality)

Point of Measurement: usually centre,

-effective point of measurement for cylindrical

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Basic quantities and notation: detector's absorbed-dose sensitivity

$$S_{\mathbf{AD,med}}(D, \dot{D}, Q, \theta, \phi) = \frac{M_{\mathbf{det}}(D, \dot{D}, Q, \theta, \phi)}{D_{\mathbf{med}}(Q)}$$

Not detector sensitivity: must specify quantity referred to (here D_{med}).

Not detector response, since this is used so many ways.

A measured quantity which can not be calculated by usual Monte Carlo codes, without additional assumptions

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Basic quantities and notation: detector's kerma sensitivity

$$S_{\mathrm{K,med}}(D, \dot{D}, Q, \theta, \phi) = \frac{M_{\mathrm{det}}(D, \dot{D}, Q, \theta, \phi)}{K_{\mathrm{med}}(Q)}$$

cf the detector's absorbed-dose sensitivity.

Notation must include ",med" where med will frequently be air, to avoid confusion with

$$S_K$$

which is a brachytherapy source's air kerma strength

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Basic quantities and notation: relative air kerma/dose sensitivity

$$S^{\mathrm{rel}}_{\mathrm{AD,med}}(D,\dot{D},Q,\theta,\phi) = \frac{S_{\mathrm{AD,med}}(D,\dot{D},Q,\theta,\phi)}{S_{\mathrm{AD,med}}(D,\dot{D},Q_0,\theta,\phi)}$$

$$S^{\mathrm{rel}}_{\mathrm{K,med}}(D,\dot{D},Q,\theta,\phi) = \frac{S_{\mathrm{K,med}}(D,\dot{D},Q,\theta,\phi)}{S_{\mathrm{K,med}}(D,\dot{D},Q_0,\theta,\phi)}$$

Sometimes called response or sensitivity in literature but these terms are not adequate.

Dimensionless quantities

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Basic quantities and notation: calibration coefficients

absorbed dose calibration coefficient

$$N_{D,w} = \frac{D_{\rm water}(Q)}{M_{\rm det}(Q)} \qquad [Gy/rdg]$$

air kerma calibration coefficient

$$N_K(Q) = \frac{K_{\rm air}(Q)}{M_{\rm det}(Q)} \qquad [Gy/rdg]$$

Coefficients rather than factors since they change units (factors are dimensionless)

$$N_{D,w}(Q) = \frac{D_{\rm water}(Q)}{M_{\rm det}(Q)} = \frac{1}{S_{\rm AD,med}(Q)}$$

Calibration coefficient is inverse of sensitivity

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Dosimeter Characteristics

Often dealt with separately, but must confirm their independence for a detector.

eg is the energy dependence of LiF independent of the size of the detector?

- Environmental & measurement corrections
  - dose rate dependence
  - background correction
  - T,P,polarity, recombination
- intrinsic linearity
- energy dependence
  - intrinsic energy dependence
  - absorbed-dose energy dependence
- directional dependence
- spatial resolution/size effects

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Environmental and measurement corrections

If reading sensitive to environmental or measurement conditions, then it is common to correct the reading to some reference conditions

- -ion chamber
  - -reference temperature, pressure, humidity
  - -100 % collection efficiency
  - -polarity correction
- -Fricke dosimeter
  - -correct to reference temperature for irradiation and readout

$$M_{\mathrm{det}}(T_0, P_0, H_0) = k_{\mathrm{env}}(T, P, H)k_{dr}(M_{\mathrm{det}}^{\mathrm{raw}}(\dot{D}))M_{\mathrm{det}}^{\mathrm{raw}}(T, P, H, \dot{D})$$

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ion chamber

$$k_{\mathrm{env}}(T, P) = P_{tp}(T, P) = \frac{273.2 + T}{273.2 + 22.0} \times \frac{101.33}{P}$$

Environmental and measurement corrections: background

If a background reading needs to be subtracted (e.g for a TLD reading or for leakage current with an ion chamber):

$$k_{\mathrm{env}}^{\mathrm{bkgd}} = \left(1.0 - \frac{M_{\mathrm{det}}^{\mathrm{bkgd}}}{M_{\mathrm{det}}} \right)$$

$$k_{\mathrm{env}}^{\mathrm{bkgd}} M_{\mathrm{det}} = M_{\mathrm{det}} - M_{\mathrm{det}}^{\mathrm{bkgd}}$$

dose-rate dependence

A detector's reading may also depend on the dose rate. It is corrected to reference conditions where k_{dr} = 1.00

$$M'_{\rm det}(\dot{D}) = k_{dr}\left(M^{\rm raw}_{\rm det}(\dot{D})\right) M^{\rm raw}_{\rm det}(\dot{D})$$

Note k_{dr} is a function of raw reading, not dose rate since that is not known until after this correction is made.

Ion chambers: P_{ion} is an example of k_{dr}

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intrinsic linearity

Is the dose proportional to the detector reading?

$$D_{\mathrm{det}}(D) = \alpha k_l(M_{\mathrm{det}}(D))M_{\mathrm{det}}(D)$$

k_l is the intrinsic linearity which is unity for some reference dose.

If k_l is unity, detector is said to be *linear*.

i.e. if the dose doubles, the reading doubles.

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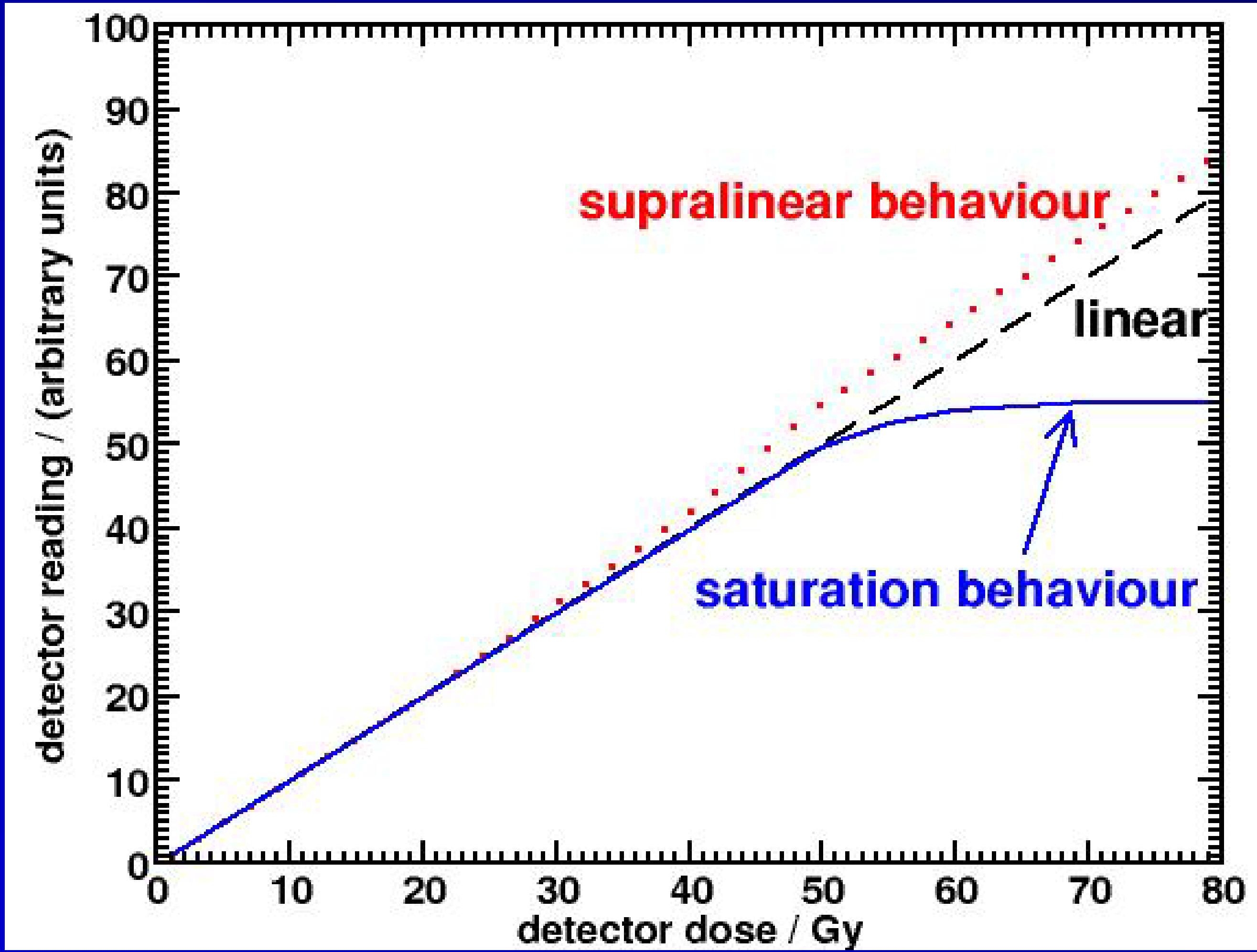
non-linear behaviour

For some detectors the response is not linear.

Some systems have more complex behaviour:

eg radiographic film



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energy dependence of the detector: intrinsic energy dependence

Overall energy dependence is broken into two components

Intrinsic energy dependence of detector relates reading of detector to dose to detector

$$D_{\mathrm{det}}(Q) = k_{bq}(Q) M_{\mathrm{det}}(Q)$$

Ideally $k_{bq}(Q)$ is a constant -it is for ion chambers

$$k_{bq}(Q) = \frac{\left(\frac{W}{e}\right)}{m_{\mathrm{gas}}}$$

k_{bq} is so frequently constant that it is often overlooked entirely.

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energy dependence of the detector: intrinsic energy dependence

-k_{bq} is often assumed to be unity but this **must be verified** for all detectors

-TLD reading per unit dose to the TLD for low energy x-rays is thought to vary by 5 to 15% because of the high LET in these beams (see Ch 14 and 24 for further discussion).

-Fricke reading per unit dose to the Fricke dosimeter varies by 1% from Co-60 to 20 MV.

k_{bq} cannot be calculated with Monte Carlo. At best the overall energy dependence is measured and k_{bq} deduced using Monte Carlo.

energy dependence of the detector: absorbed-dose energy dependence

The absorbed-dose energy dependence of the detector is widely recognized and relates dose to medium of interest to dose to detector.

$$D_{\mathrm{med}}(Q) = f(Q) D_{\mathrm{det}}(Q)$$

$D_{med}(Q)$ is dose at the point of measurement in the absence of detector

f(Q) can, in principle, be calculated by Monte Carlo.

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energy dependence of the detector: absorbed-dose energy dependence

In ion chamber dosimetry

$$f(Q) = \left(\frac{\overline{L}}{\rho}\right)^{\text{med}}_{\text{gas}} P_{\text{wall}} P_{\text{cel}} P_{\text{stem}} P_{\text{repl}}$$

For TLD dosimetry in low-energy photon beams, a simple approximation is

$$f(Q) \approx \left(\frac{\overline{\mu}_{en}}{\rho}\right)^{\text{med}}_{\text{TLD}}$$

but in practice one must use a Monte Carlo calculation since this only holds if photon fluence is same in both media & only if detector is a photon detector.

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energy dependence of the detector

$$D_{\mathrm{det}}(Q) = k_{bq}(Q) M_{\mathrm{det}}(Q)$$

$$D_{\mathrm{med}}(Q) = f(Q) D_{\mathrm{det}}(Q)$$

$$N_{D,w} = \frac{D_{\mathrm{med}}}{M_{\mathrm{det}}} = f(Q) k_{bq}(Q)$$

Since $N_{D,w}$ includes k_{bq} which cannot be calculated using Monte Carlo, we cannot calculate the calibration coefficient or its inverse, the absorbed-dose sensitivity ($S_{AD,water}$) without making explicit assumptions about k_{bq}.

The same applies to variations in these quantities with beam quality.

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other dependencies

directional dependence

Can be part of f(Q) and k_{bq}(Q), and if strong dependence the protocol for detector's use will include info on the orientation of the detector

spatial resolution/size effects

Can be part of f(Q) and k_{bq}(Q) but for situations with small beams or near edges of beams, it may be useful to separate out these effects

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