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

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

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

May need correction for T, P, H, polarity effects or ion recombination etc
Basic quantities and notation: dose to the detector

\[ D_{\text{det}}(D, \dot{D}, Q, \theta, \phi) \]

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 \( M_{\text{det}} \)
Basic quantities and notation: dose or kerma to medium

\[ D_{\text{med}}(Q) \quad K_{\text{med}}(Q) \]

- Quantities at point of measurement in medium 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
Basic quantities and notation: detector’s absorbed-dose sensitivity

\[ S_{\text{AD,med}}(D, \dot{D}, Q, \theta, \phi) = \frac{M_{\text{det}}(D, \dot{D}, Q, \theta, \phi)}{D_{\text{med}}(Q)} \]

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

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.
Basic quantities and notation: detector’s kerma sensitivity

\[ S_{K,\text{med}}(D, \dot{D}, Q, \theta, \phi) = \frac{M_{\text{det}}(D, \dot{D}, Q, \theta, \phi)}{K_{\text{med}}(Q)} \]

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
Basic quantities and notation: relative air kerma/dose sensitivity

\[ S_{\text{AD,med}}^{\text{rel}}(D, \dot{D}, Q, \theta, \phi) = \frac{S_{\text{AD,med}}(D, \dot{D}, Q, \theta, \phi)}{S_{\text{AD,med}}(D, \dot{D}, Q_0, \theta, \phi)} \]

\[ S_{\text{K,med}}^{\text{rel}}(D, \dot{D}, Q, \theta, \phi) = \frac{S_{\text{K,med}}(D, \dot{D}, Q, \theta, \phi)}{S_{\text{K,med}}(D, \dot{D}, Q_0, \theta, \phi)} \]

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

Dimensionless quantities
Basic quantities and notation: calibration coefficients

absorbed dose calibration coefficient

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

air kerma calibration coefficient

\[ N_K(Q) = \frac{K_{\text{air}}(Q)}{M_{\text{det}}(Q)} \quad [\text{Gy/rdg}] \]

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

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

Calibration coefficient is inverse of sensitivity
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
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

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

\[ k_{\text{env}}(T, P) = P_{\text{tp}}(T, P) = \frac{273.2 + T}{273.2 + 22.0} \times \frac{101.33}{P} \]
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):

\[ k_{\text{env}}^{\text{bkgd}} = \left( 1.0 - \frac{M_{\text{det}}^{\text{bkgd}}}{M_{\text{det}}} \right) \]

\[ k_{\text{env}}^{\text{bkgd}} M_{\text{det}} = M_{\text{det}} - M_{\text{det}}^{\text{bkgd}} \]
dose-rate dependence

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

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

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 $k_{dr}$
**intrinsic linearity**

Is the dose proportional to the detector reading?

\[ D_{\text{det}}(D) = \alpha k_l \left( M_{\text{det}}(D) \right) M_{\text{det}}(D) \]

\( k_l \) 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.
non-linear behaviour

For some detectors the response is not linear.

Some systems have more complex behaviour:

eg radiographic film
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

\[ D_{det}(Q) = k_{bq}(Q) M_{det}(Q) \]

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

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

\( k_{bq} \) is so frequently constant that it is often overlooked entirely.
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.
The absorbed-dose energy dependence of the detector is widely recognized and relates dose to medium of interest to dose to detector.

\[ D_{\text{med}}(Q) = f(Q)D_{\text{det}}(Q) \]

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

\( f(Q) \) can, in principle, be calculated by Monte Carlo.
energy dependence of the detector: absorbed-dose energy dependence

In ion chamber dosimetry

\[ f(Q) = \left( \frac{\bar{L}}{\rho} \right)^{\text{med}} \frac{P_{\text{wall}} P_{\text{cel}} P_{\text{stem}} P_{\text{repl}}}{P_{\text{gas}}} \]

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

\[ f(Q) \approx \left( \frac{\bar{\mu}_{\text{en}}}{\rho} \right)^{\text{med}} \]

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.
energy dependence of the detector

\[ D_{\text{det}}(Q) = k_{\text{bq}}(Q)M_{\text{det}}(Q) \]
\[ D_{\text{med}}(Q) = f(Q)D_{\text{det}}(Q) \]
\[ N_{D,w} = \frac{D_{\text{med}}}{M_{\text{det}}} = f(Q)k_{\text{bq}}(Q) \]

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

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