Investigation of the energy dependence of $W_{\text{air}}$ in high energy electron beams

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Radiotherapy clinic: standard dosimetry

Farmer Ion chamber (IC)
The underlying physics

Radiation $\rightarrow$ Loss of energy
The underlying physics

Radiation $\rightarrow$ Loss of energy $\rightarrow$ Ionization of air
The underlying physics

Radiation → Loss of energy → Ionization of air → Charge collection

\[ Q_{\text{gas}} \]
Measurement vs quantity of interest

Radiation → Loss of energy → Ionization of air → Charge collection

$Q_{\text{gas}}$

What we are able to measure
Measurement vs quantity of interest

Radiation $\rightarrow$ Loss of energy $\rightarrow$ Ionization of air $\rightarrow$ Charge collection $Q_{gas}$

Related to the absorbed dose

$$D_{gas} = \frac{\langle d\epsilon \rangle}{dm} \approx \frac{\text{Energy deposited}}{\text{Mass}}$$

What we are able to measure
How to relate them?

Radiation $\rightarrow$ Loss of energy $\rightarrow$ Ionization of air $\rightarrow$ Charge collection $Q_{\text{gas}}$

Related to the absorbed dose

$D_{\text{gas}} = \frac{\langle d\epsilon \rangle}{dm} \approx \frac{\text{Energy deposited}}{\text{Mass}}$ $\propto \frac{Q_{\text{gas}}W_{\text{air}}}{m_{\text{gas}}}$

What we are able to measure

$W_{\text{air}}$
Consensus on $W_{\text{air}}$

Radiation $\rightarrow$ Loss of energy $\rightarrow$ Ionization of air $\rightarrow$ Charge collection

$D_{\text{gas}} \quad \leftarrow \quad W_{\text{air}} \quad \rightarrow \quad Q_{\text{gas}}$

$W_{\text{air}}$ is the mean energy required to create ion pair in air
For electron energies well above 10 keV, [...], in the absence of any data to the contrary, $W_{\text{air}}$ is taken to be independent of energy.

$W_{\text{air}} = 33.97 \pm 0.12$ eV
Re-analysis of Domen & Lamperti by Tessier et al.

$W_{\text{air}}$ (eV)

Electrons energy in air cavity (MeV)

Polynomial fit $\pm \sigma$
Re-analysis D&L by F.T.
ICRU #90 $\pm \sigma$
Re-analysis of Domen & Lamperti by Tessier et al.

Investigate $W_{\text{air}}$ value in high energy beam

Electrons energy in air cavity (MeV)

$W_{\text{air}}$ (eV)

Polynomial fit ± $\sigma$

Re-analysis D&L by F.T.

ICRU #90 ± $\sigma$
How can we obtain $W_{\text{air}}$?

$$D_{\text{gas}} = \frac{Q_{\text{gas}}}{m_{\text{gas}}} W_{\text{air}}$$

$$W_{\text{air}} = \frac{D_{\text{gas}} m_{\text{gas}}}{Q_{\text{gas}}}$$
How can we obtain $W_{\text{air}}$?

$$D_{\text{gas}} = \frac{Q_{\text{gas}}}{m_{\text{gas}}} W_{\text{air}}$$

$$W_{\text{air}} = \frac{D_{\text{gas}} m_{\text{gas}}}{Q_{\text{gas}}}$$

Measurement of charge in ion chamber (corrected)
How can we obtain $W_{air}$?

\[ D_{gas} = \frac{Q_{gas}}{m_{gas}} W_{air} \]

\[ W_{air} = \frac{D_{gas} \cdot m_{gas}}{Q_{gas}} \]

- Volume x density
- Measurement of charge in ion chamber (corrected)
How can we obtain $W_{\text{air}}$?

\[ D_{\text{gas}} = \frac{Q_{\text{gas}}}{m_{\text{gas}}} W_{\text{air}} \]

$W_{\text{air}} = \frac{D_{\text{gas}} m_{\text{gas}}}{Q_{\text{gas}}}$

Hard to measure...

Volume x density

Measurement of charge in ion chamber (corrected)
How can we obtain $W_{\text{air}}$?

\[ D_{\text{gas}} = \frac{Q_{\text{gas}}}{m_{\text{gas}}} W_{\text{air}} \]

Calorimetric measurement

\[ W_{\text{air}} = \frac{D_{\text{med}} m_{\text{gas}}}{Q_{\text{gas}}} \left( \frac{D_{\text{gas}}}{D_{\text{med}}} \right)^{MC} \]

Monte Carlo
Detector phantom

Graphite Calorimeter within Polystyrene box

Graphite Ion Chamber within Polystyrene box
Radiation set-up

Electron applicator

Al scatterer

Vicker linac

2 beam monitoring IC

1.5 m

2 thimble IC

Graphite Ion Chamber within Polystyrene box

Graphite Calorimeter within Polystyrene box
Variation of configurations

**Graphite buildup**

Outer **OR** inner to the Styrofoam  
Between 0 to 4 cm

**Irradiation time**

15 or 30 seconds

**Electron beam energy**

20 and 35 MeV
Results

Electrons energy in air cavity (MeV)

Present work

ICRU, $\chi^2 = 13$, dof=8, $p=0.10$

Poly. fit. D&L, $\chi^2 = 11$, dof=5, $p=0.06$
Results

Electrons energy in air cavity (MeV) vs. $W_{air}$ (eV)

- **Present work**
  - $33.78 \pm 0.12$ eV
  - 0.56%

- **ICRU**
  - $33.97 \pm 0.12$ eV
  - $\chi^2 = 13$, dof=8, $p=0.10$

- **Present work avg.**
  - $33.78 \pm 0.12$ eV
  - $\chi^2 = 3.8$, dof=8, $p=0.88$
Results

Electrons energy in air cavity (MeV)

- Present work
- Poly. fit. D&L, $\chi^2 = 11$, dof=5, $p=0.06$
- ICRU, $\chi^2 = 13$, dof=8, $p=0.10$
- Present work avg., $\chi^2 = 3.8$, dof=8, $p=0.88$
Results

Electrons energy in air cavity (MeV)

- Present work
- Poly. fit. D&L, $\chi^2 = 11$, dof=5, p=0.06
- ICRU, $\chi^2 = 13$, dof=8, p=0.10
- Present work avg., $\chi^2 = 3.8$, dof=8, p=0.88
Results consistent with a constant value of $33.78 \pm 0.12$ eV

Inconclusive on the energy dependence

Further focus is required:

- Increase number of measurements
- Increase energy range
- Improve uncertainties
Come see my poster for more details

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