Energy Monitoring Device for Electron Beam Facilities

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Introduction

The electron beam energy in commercial radiation processing is one of the critical parameters for quality assurance and quality control since it determines the size of the product box that can be processed and a variation of the energy affects the absorbed dose distribution in the product under irradiation.

Standards procedures require that the beam energy be:

- determined during the facility qualification;
- monitored and controlled during routine irradiation.
Examples of dose distribution in uniform material:

10 MeV

Single side irradiation
(water, 5 cm)

Double side irradiation
(water, 9 cm)

9.8 MeV

Simulations obtained with the software ModeRTL, Version 2.6.
Amongst different methods for measuring the electron beam energy, the study of the depth-dose distribution in a homogeneous reference material is the widely used technique.

Empirical energy-range relations for

**mean electron energy:**

\[ E_a = (2.33 \text{ MeV} \cdot \text{cm}^{-1}) \times (R_{50} \text{ cm}) \]

(5 MeV \( \leq E_a \leq 35 \text{ MeV}, \text{in H}_2\text{O phantom} \))

**most probable electron energy:**

\[ E_p = (5.09 \text{ MeV} \cdot \text{cm}^{-1}) \times (R_p \text{ cm}) + 0.20 \text{ MeV} \]

(5 MeV \( \leq E_p \leq 25 \text{ MeV}, \text{in Al phantom} \))

Another possible method, which is the subject of this work, is the study of the influence of the electron beam energy on the charge distribution with depth in homogeneous absorbers.
The basic idea:

- $E_p'' < E_p$
- $E_p' > E_p$
The first device:
K. Mehta, J. Barnard, W. Stanley and A. Unger

*Experience with e-beam process dosimetry at the Whiteshell Irradiator*

International Symposium on High Dose Dosimetry for Radiation Processing
Vienna 5-9 November 1990

The actual device:

- Aluminium cage: 140 mm x 140 mm x 100 mm (h), 10 mm thick
- Front plate: 2, 5 or 12 mm
- Back plate: 25 mm
- Ceramic pillars
- 5 mm air gap
- BNC connectors to A-meters
- To ground
Definition of the “energy ratio” (E.R.):

\[ E.R. = \frac{I_1}{I_1 + I_2} \]

where:

- \( I_1 \) is the current from the front plate
- \( I_2 \) is the current from the back plate
## The previous tests

<table>
<thead>
<tr>
<th>Location</th>
<th>Beam characteristics</th>
<th>Thickness of the front absorber (the back absorber was always 25 mm)</th>
<th>Energy range MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISOF-CNR Bologna (Italy)</td>
<td>Research L-band LINAC 0.2 - 5 μs pulses at 50 Hz energy varied changing the pulse length and the beam current</td>
<td>12 mm</td>
<td>6.5 - 11.5</td>
</tr>
<tr>
<td>Institute of Isotopes Budapest (Hungary)</td>
<td>Research Tesla LPR-4 LINAC 2.6 μs pulses at 50 Hz energy varied changing the beam current</td>
<td>5 mm</td>
<td>4 - 6</td>
</tr>
<tr>
<td>FE-MA Co. Ltd. Budapest (Hungary)</td>
<td>Commercial LUE-8 LINAC 3.6 μs pulses at 50 Hz beam scanned at 5 Hz energy varied changing the magnetron high voltage and the beam current</td>
<td>5 mm</td>
<td>4 - 6.5</td>
</tr>
<tr>
<td>Gambro-Dasco Medolla (Italy)</td>
<td>Commercial Rhodotron TT-100 “continuous” beam, 0.5 - 2.7 mA beam scanned at 100 Hz energy does not vary</td>
<td>12 mm</td>
<td>10</td>
</tr>
</tbody>
</table>
Several measuring techniques adopted:

- measurement of the charge deposited into the absorbers through the integration of the current for a fixed time, using digital current integrators (EG&G ORTEC 439) [ISOF, LINAC]

- measurement of the currents using EG&G ORTEC 439, used as current monitor [Gambro Dasco Spa, Rhodotron]

- dedicated measuring instrument realized using an integrated circuit, with ultra low bias and fast slew rate, selected so that its offset voltage and its temperature drift were as low as possible, hardwired in the current amplifier configuration [Institute of Isotopes, LINAC and FE-MA Co. Ltd., LINAC]
The previous results

\[ E_p, \text{ MeV} \]

Energy ratio

- FEMA Co. Ltd., Budapest, LUE-8 LINAC
- ISOF-CNR, Bologna, Vickers L-band LINAC
- Institute of Isotopes, Budapest, Tesla LPR-4 LINAC
- Gambro Dasco Spa, Medolla (MO), TT100 Rhodotron

\[ E_p, \text{ MeV} \]
Aim of the actual work:
- extension of the method to a lower energy region (around 2 MeV)
- tests on the sensitivity performances of the device

Experimental:

*Electron beam source:*
0.5 - 2.4 MeV; 1 - 125 µA Van De Graaff electron accelerator
Aérial (Strasbourg, France)

*Energy monitoring device:*
Thickness of front absorber plate: 2 mm
Measurement of the currents: electrometer Keithley 610B or multimeter (ITT Metrix MX512)

*Energy measurement:*
$E_p$: B3 radiochromic film dosimeters placed in within several polystyrene foils (stack technique)
Depth-dose curves in polystyrene (PS).

International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators
4-8 May 2009 Vienna
Nominal electron beam energy vs. the most probable electron beam energy:

<table>
<thead>
<tr>
<th>Nominal electron beam energy* (as set by the high voltage control)</th>
<th>Practical electron beam range measured in PS ( (\rho = 1.06 \text{ g}\cdot\text{cm}^{-3}) )</th>
<th>Practical electron beam range scaled to water ( (\rho = 1 \text{ g}\cdot\text{cm}^{-3}) )</th>
<th>Calculated most probable energy ( E_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeV</td>
<td>cm</td>
<td>cm</td>
<td>MeV</td>
</tr>
<tr>
<td>1.5</td>
<td>0.62</td>
<td>0.64</td>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
<td>0.86</td>
<td>0.88</td>
<td>2.0</td>
</tr>
<tr>
<td>2.4</td>
<td>1.08</td>
<td>1.11</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*Calibrated during the facility installation using the technique of foil activation
Response of the energy monitoring device using the electrometer.
Test of the sensitivity of the energy monitoring device; measurements with electrometer (●) and multimeter (□).
Conclusions

The energy monitoring device:

- able to monitor variations in the electron beam in the range of 1.5 - 2.4 MeV (2 mm front absorber)

- sensitivity of at least 40 keV

- robust and immediate response: easy integration in the control system of an electron beam irradiation facility

- the range of possible beam energy can be easily accommodated by properly selecting the thickness of the two absorber plates

- a variety of techniques can be adopted to measure the currents (or the charges) generated by accumulated electrons in the absorber plates

- for accurate measurements, either an electrometer or a dedicated circuit is needed
Future developments:

integration of a dedicated energy monitoring device, equipped with dedicated electronic, in research or industrial facilities for on-line monitoring of the electron beam energy. (Aérial, Strasbourg)
Acknowledgements
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Thank you!