Development of Graphite Calorimetry at the NPL for Proton Beam Therapy

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Background

- Current protocols based on chambers calibrated in other beam types (electrons, Co60)
- Preferred method of transfer of calibration from primary standard to user is cross calibration in a beam of the same or similar beam quality.
- UK protons are coming, well actually they have already been here since 1989!
- Clatterbridge/NPL collaboration since 1999
- 2001 NPL SR project to examine issues surrounding reference dosimetry for proton beams
- 5th April 2012 UK government announced two NHS “high” energy facilities at Christie and UCLH
Aim of the original project was to explore the variation of the current recommendations of dosimetry protocols and the feasibility of building a primary standard to routinely operate in the clinical department.

Visit and meeting at Clatterbridge 6/11/02

Present: Andrzej Kacperek (AK), Russel Thomas (RAST), Frank Verhaegen (FV), Hugo Palmans (HP)

13:30 Delicious lunch at 400 years old pub

14:30 Visit to workshop and proton treatment room

Inventory of equipment available at Clatterbridge:
- Milling-machine: accuracy 0.005mm, working area 400 mm x 280 mm
  - Plastics, graphite, aluminium, brass, ...
  - We could have phantom inserts, etc. made there at no cost for NPL. For parts that need construction, provide drawing + parts that have to be inserted such as ion chamber.
- Computer dedicated to research (we could install MCNPX here!)

ACTION: FV will send AK procedure to obtain MCNPX from NEA database
- Beam line:
Publications resulting directly from work conducted between NPL/CCC plus at least a further 4/5 in preparation

- R Thomas, H Palmans, A Kacperek, S Duane, “Low energy proton beam dosimetry with plane-parallel chambers using NPL electron and $^{60}$Co calibrations,” Published in proceedings of the ARPANSA workshop on Recent Advances in Absorbed Dose Standards 19-21 August, 2003


“Of course, our other articles and book chapters (29) we have published on proton or carbon ion dosimetry have also indirectly been enabled by our collaboration with Clatterbridge.”


Calorimetry
Graphite calorimetry for protons CCO
Graphite calorimetry results CCO

<table>
<thead>
<tr>
<th>Calibration beam quality</th>
<th>$D_{W,SPGC}/D_{W,IC}$</th>
<th>modulated</th>
<th>non-modulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>0.996</td>
<td>1.019</td>
<td></td>
</tr>
<tr>
<td>$q_{e19}$</td>
<td>0.983</td>
<td>1.004</td>
<td></td>
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</tbody>
</table>
1925 Triumph 500cc Model P
Design of new calorimeter

- Vacuum vessel - graphite mantle
- O ring seal
- Annular PCB
- Outer jacket
- Inner jacket
- Core
- Tubes containing wires, leading to vacuum system
Quasi-adiabatic mode of operation;

Outer jacket of calorimeter is maintained at a constant temperature, usually a few degrees C above the ambient temperature of the room. The core and inner jacket are not controlled and allowed to drift. The absorbed dose, \( D_g \), is obtained by multiplying the temperature rise in the graphite core, \( \Delta T_g \) (corrected for heat transfers), by the specific heat capacity, \( c_p^g \) of graphite:

\[
D_g = c_p^g \cdot \Delta T_g
\]
Adiabatic Mode
Isothermal mode of operation;

Jackets and core are maintained at constant temperature. The dose delivered to the core by irradiation, $D$, can be calculated from electrical substitution, where $\Delta E_{\text{elec}}$ is the change in electrical energy supplied to the core during irradiation and $m_{\text{core}}$ is the mass of the core.

$$D_g = \frac{\Delta E_{\text{elec}}}{m_{\text{core}}}$$
Isothermal Mode
Calorimeter / Ionisation chamber set up at CCO
Chamber measurements in Water

Set up at LNS Catania, for Alpha & Carbon ion beams
“Portable” Proton Calorimeter
“We need to test this table will hold the weight with something we can afford to loose if it breaks……”
Summary

- Device has been successfully transported by road/sea/air to Sicily, Japan, Prague and Liverpool
- Demonstrated that a robust and portable calorimeter can be built to the level required of a primary standard and operate successfully in the clinical setting
- Initial derivation of the W value shows good agreement with previously derived data and inline with published value
- Traceability & comparability to existing UK dosimetry protocols
- Support clinical trials and biological investigation
- IPEM backing for UK proton reference dosimetry code of practice
Thank you, and over to Stuart....
The National Measurement System is the UK’s national infrastructure of measurement Laboratories, which deliver world-class measurement science and technology through four National Measurement Institutes (NMIs): LGC, NPL the National Physical Laboratory, TUV NEL The former National Engineering Laboratory, and the National Measurement Office (NMO).
Derivation of \((w_{\text{air}})_p\) from calorimeter measurements

\[
K_Q = \frac{N_{D,w,p}}{N_{D,w,c}} = \frac{D_{w,\text{cal},p}}{M_p} \approx \frac{(w_{\text{air}})_p \cdot (s_{w,\text{air}})_p \cdot p_p}{(W_{\text{air}})_c \cdot (s_{w,\text{air}})_c \cdot p_c}
\]

\[
(w_{\text{air}})_p = \frac{D_{w,\text{cal},p} \cdot (W_{\text{air}})_c \cdot (s_{w,\text{air}})_c \cdot p_c}{M_p \cdot N_{D,w,c} \cdot (s_{w,\text{air}})_p \cdot p_p}
\]
W-value calculated for measurement in modulated beam
W-value calculated for measurement in unmodulated beam
W- value calculated for measurement in modulated beam (corrected!)
Proton Calorimeter "road trip"