Values of the non-reference condition correction factor $k_{NR}$ for high-energy photon radiations

N. Chofer $^{1,*}$, D. Harder $^3$, B. Poppe $^{1,*}$

$^1$ Working Group Medical Radiation Physics, Carl von Ossietzky University Oldenburg, Germany
$^2$ Piùs-Hospital, Clinic for Radiotherapy and Oncology, Georgstrasse 12, Oldenburg, Germany
$^3$ Prof. em., Medical Physics and Biophysics, Georg-August University Göttingen, Germany

Purpose / Objective
The radiation quality correction factor $k_Q$ is used to account for changes of detector response under reference conditions (photons of quality index Q, at a point on the beam axis at 10 cm water depth for a 10 x 10 cm$^2$ field) compared with calibration conditions ($^{60}$Co gamma radiation, for the same geometry). Clinical dosimetry, however, is often performed under non-reference conditions, i.e. at varying depths, field sizes and off-axis distances including out-of-field points. The non-reference condition correction factor $k_{NR}$ was introduced to account for the associated changes of detector response. $k_{NR}$ has a value of 1 under reference conditions. In this study, Monte Carlo methods were used to evaluate $k_{NR}$ for an air-filled Farmer type ion chamber (PTW Freiburg), two TLD detector types LiF:Mg,Ti and LiF:Mg,Cu,P and two types of Si diode, the shielded EDP-10 and the unshielded EDD-5.

Materials and Methods
Using Monte Carlo codes BEAMnrc and FLURZnrc, complete photon fluence spectra $\Phi_E(E)$ for 6 and 15 MV photon beams from a Siemens Primus linac were scored in a large water phantom. The energy-dependent responses $r_t(E)$ of detector type 1 for monoenergetic photons, valid for a Farmer ion chamber (type NE2571) $^2$, for TLD types LiF:Mg,Ti $^3$ and LiF:Mg,Cu,P $^4$, and for the shielded EDP-10 and unshielded EDD-5 Si diodes $^5$ were taken from the literature. By combining spectra $\Phi_E(E)$, response functions $r_t(E)$ and mass energy absorption coefficients of water, $\mu_E(E)/\rho$, the mean detector response $Y_t(x)$ under general conditions x was calculated and compared to its value $Y_t(x_{ref})$ under reference conditions. Factor $k_{NR}$ was obtained as the ratio $Y_t(x_{ref})/Y_t(x)$. As a specialty for small field dosimetry, a 4 x 4 cm$^2$ field was used as the reference field size.

Results
Within the field limits, $k_{NR}$ deviated less than 0.5 % from unity for the Farmer chamber but was largest for the EDD-5 diode, by up to 16 % at 6 MV due to overresponse for fields larger than 10 x 10 cm$^2$. For smaller fields, $k_{NR}$ variations ranged up to 6 %. Results for the EDP-10 diode were similar to those of the Farmer chamber, with slight underresponse for small fields, with up to 5 % at larger fields. For the TLDs, the $k_{NR}$ in-field values varied ±1 % with the LiF:Mg,Cu,P detector underresponding at larger fields; the reverse was the case for the LiF:Mg,Ti detector. For out-of-field regions, $k_{NR}$ values for the Farmer chamber were lowered by up to 2 %, and were reduced by up to 60 % respectively 20 % for the EDD-5 and EDP-10 diodes due to their overresponse. $k_{NR}$ values for both the LiF:Mg,Cu,P and LiF:Mg,Ti TLDs varied at most by 15 %.

Using corresponding values of mean photon energy $E_m = \int E \Phi_E(E) dE / \int \Phi_E(E) dE$, a simple correlation between $k_{NR}$ for TLD LiF:Mg,Ti chips $^5$ and $E_m$ has been obtained and is supported by experimental results as shown in fig 1.

For narrow fields, it is advantageous to use a 4 x 4 cm$^2$ reference field (non-reference condition correction factor $k_{NR}(x_{cal,ref})$) as illustrated for a 10 x 10 cm$^2$ field in Table 1.

Table 1. Values of $k_{NR}(x_{cal,ref})$ for various detectors

<table>
<thead>
<tr>
<th>Detector type</th>
<th>6 MV</th>
<th>15 MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer chamber</td>
<td>0.999</td>
<td>0.998</td>
</tr>
<tr>
<td>TLD LiF:Mg,Ti</td>
<td>1.008</td>
<td>1.003</td>
</tr>
<tr>
<td>TLD LiF:Mg,Cu,P</td>
<td>0.993</td>
<td>0.997</td>
</tr>
<tr>
<td>Shielded diode EDP-10</td>
<td>1.004</td>
<td>1.002</td>
</tr>
<tr>
<td>Unshielded diode EDD-5</td>
<td>1.040</td>
<td>1.014</td>
</tr>
</tbody>
</table>

Conclusions
Generally, $k_{NR} < 1$ indicates detector overresponse, while $k_{NR} > 1$ corrects for underresponse. The varying low-energy component of the photon spectrum at the point of interest accounts for $k_{NR}$ variations under non-reference conditions. Thus, air-filled ion chambers show only small $k_{NR}$ variations. For non-water equivalent detectors, $k_{NR}$ variations depend on the detector response at low photon energy, as shown, e.g., by the small $k_{NR}$ values for the unshielded EDD-5 diode in out-of-field regions. For narrow fields, a small 4 x 4 cm$^2$ reference field is recommended with correction factor $k_{NR}(x_{cal,ref})$ varying almost negligibly from $k_{NR}$ except for unshielded Si diodes. A major result of this project is the possibility to infer $k_{NR}$ using the unique relationship established between the mean photon energy, $E_m$ and $k_{NR}$ for TLD LiF:Mg,Ti in accordance with experimental findings from other authors.

Literature
1. Kawrakow and Rogers 2003 NRCC Report PIRS-701, Ottawa
2. Wulf and Zink 2011 Personal communication