Dose calculation algorithm for external neutron radiotherapy based on pencil beam method

We investigated availability of pencil beam (PB) algorithm for external neutron radiotherapy treatment planning. In order to use multi-group approach we calculated PB dose kernels for range of neutron energies in general purpose Monte-Carlo (MC) program MCNP, thus resulting dose kernel for arbitrary spectrum will be a superposition of this energy bin kernels. We have tested this approach on four common spectra ranged from BNCT spectrum to D-T generator spectrum.

Two approximations for scattered neutrons dose kernels $K_s$ were used:

1. $K_{s,PB} = K_s(r, z) = \sum_{i=1}^{N} C_i(z) \frac{\exp(-k_i(z) * r)}{r}$

2. $K_{s,PB} = K_s(r, z) = \sum_{i=1}^{N} C_i(z) \exp(-k_i(z) * r^2)$,

Here is $r$ – distance from kernel axis, $z$ – depth in phantom.

Both approximations give good results while (2) has some integration speed advantages in case of rectangular fields.

Water was chosen as reference phantom material. To evaluate necessary corrections we took several tissues compositions from ICRU-33 report. Corrections seem to be vital for fast neutron therapy (Table 1) while for low energy neutrons it’s not essential.

Comparison of PB dose calculation with MC calculations was used to benchmark investigated approach. Several geometries were used, including 2D detector array in human chest prototype phantom. Example of gamma analysis for Cf-252 spectrum calculations (MC vs PB with corrections) is shown on Fig.1. Summary of gamma analysis results are given in Table 1.

![Gamma Analysis](image.png)

**Figure 1.** Gamma analysis for Cf-252 spectrum calculations (MC vs PB with corrections). 10×10 cm² field in heterogeneous phantom.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>BNCT</th>
<th>Reactor</th>
<th>Cf</th>
<th>DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/o corr.</td>
<td>0,02</td>
<td>16</td>
<td>18,9</td>
<td>22,1</td>
</tr>
<tr>
<td>Corrected</td>
<td>0,08</td>
<td>0</td>
<td>0,25</td>
<td>6,9</td>
</tr>
</tbody>
</table>

Table 1. Percent of $\gamma(6 \%, 3 \text{ mm})$ fails for MC vs PB comparison inside of the field.