Sensitivity analysis to neutron dose at patient's organs according to some parameters in a linac in the case of a bladder treatment

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I. Introduction to photo-neutron problematic

I.1 Photo-neutron problematic

- The study of neutron contamination produced around medical linear accelerators was the focus of several research works, in the field, these last year's.

- In radiotherapy for treatment modes greater than 8 MV (Table 1), contamination neutrons are produced, in patient’s through \((\gamma, n)\) interaction.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number A</th>
<th>(S_p(\gamma,n))</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>2</td>
<td>2.23</td>
</tr>
<tr>
<td>Be</td>
<td>9</td>
<td>1.67</td>
</tr>
<tr>
<td>O</td>
<td>16</td>
<td>15.66</td>
</tr>
<tr>
<td>Cu</td>
<td>63</td>
<td>10.85</td>
</tr>
<tr>
<td>W</td>
<td>65</td>
<td>9.91</td>
</tr>
<tr>
<td>W</td>
<td>180</td>
<td>8.41</td>
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<tr>
<td>W</td>
<td>182</td>
<td>8.06</td>
</tr>
<tr>
<td>W</td>
<td>183</td>
<td>7.41</td>
</tr>
<tr>
<td>W</td>
<td>184</td>
<td>7.41</td>
</tr>
<tr>
<td>W</td>
<td>186</td>
<td>7.21</td>
</tr>
<tr>
<td>Au</td>
<td>197</td>
<td>8.06</td>
</tr>
<tr>
<td>Pb</td>
<td>204</td>
<td>8.4</td>
</tr>
<tr>
<td>Pb</td>
<td>206</td>
<td>8.09</td>
</tr>
<tr>
<td>Pb</td>
<td>207</td>
<td>6.74</td>
</tr>
<tr>
<td>Pb</td>
<td>208</td>
<td>7.37</td>
</tr>
</tbody>
</table>

Table 1. (NCRP 151, 79)
I. Introduction to photo-neutron problematic

I.2 Previous studies

(\gamma,n) production depends principally on:

- Accelerator manufacturing technology
- Operation mode and radiation ballistics;
- Morphology of patient
- The environment of linac
Objective of the study

1. Evaluate the photo-neutron doses at patient's organs by Monte Carlo (MC) simulation for a frequent clinical treatment i.e. bladder radiotherapy.

2. Calculate the percent risk of developing a secondary cancer in different patient's organs.
II. Methodology of work

1. Monte Carlo simulation of linac head and treatment room using MCNP5

2. Monte Carlo simulation of patient specific Phantom

3. Treatment plan simulation bladder radiotherapy

Calculations performed

- Radioprotection quantities
- Risk estimate
- Sensitivity analysis

Neutron equivalent dose at different patient’s organs

Percent Risk of developing an induced cancer

Estimate the influence of certain parameters on calculation's results
II. Methodology of work

II. 1. Monte Carlo simulation of linac head and treatment room.
II. 2. Monte Carlo simulation patient specific phantom

LINAC: VARIAN 2100C installed in radiotherapy service of CAC-Blida, Algiers, Algeria, 18MV.
II. Methodology of work

II. 1. Monte Carlo simulation of linac head and treatment room.

II.2. Monte Carlo simulation patient specific phantom

Images from TPS

Images from MCNP5-VISED

MLC geometry
Anterior posterior field

MLC geometry
Right and left lateral field
II. Methodology of work

II. 1. Monte Carlo simulation of linac head and treatment room.

II. 2. Monte Carlo simulation patient specific phantom

Representation of respective simulation stages, Stage 1: include the head accelerator and treatment room simulation, the stage 2: concern the patient environment represented with MIRD phantom MCNP model
III. Results and discussion

III.1. Neutron equivalent dose at different patient's organs

III.2. Risk of developing a secondary cancer

III.3. Sensitivity analysis

\[ H_T = \sum W_R(E_n) \cdot D_T(E_n) \]

MCNP: Tally F4

MCNP: De, DF card

Neutron fluence

Neutron dose

Neutron equivalent dose

Radiation conversion factors WR from ICRP 116

Tissues conversion factors WT from ICRP 116
III. Results and discussion

III.1. Neutron equivalent dose at different patient’s organs

III.2. Risk of developing a secondary cancer

III.3. Sensitivity analysis

✓ Organs situated in the vicinity of treatment field receive more neutron equivalent dose. And the maximum value was about 54.56 mSv, calculated for the total treatment in uterus.

✓ The minimum of neutron equivalent dose is expected to be at organs far from the target. The smallest value was 26.25 mSv, calculated at esophagus for the total treatment.

✓ Neutron equivalent dose varies according to the gantry angle.

✓ Discrepancies were found between ours results and those of Khabaz et al. 2018, where the maximum was found at uterus 32% and the minimum 0% at Stomach. This is probably due to the difference in MC linac models used in the two studies. As well as to the variation in irradiation parameters, and to the shielding room configuration.

\[ H_T = \sum W_R(E_n) \cdot D_T(E_n) \]

Figure 1. Photo-neutron equivalent dose in different organs for each gantry angles of LINAC 18MV, compared with results obtained by Khabez et al., 2018.
III. Results and discussion

III.1. Neutron equivalent dose at different patient’s organs

III.2. Risk of developing a secondary cancer

III.3. Sensitivity analysis

### Table 2

<table>
<thead>
<tr>
<th>Organ</th>
<th>( r_{T} ) ( (10^{-2}/\text{Sv}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uterus</td>
<td>0.5</td>
</tr>
<tr>
<td>Breast</td>
<td>0.2</td>
</tr>
<tr>
<td>Colon</td>
<td>0.85</td>
</tr>
<tr>
<td>Spleen</td>
<td>0.5</td>
</tr>
<tr>
<td>Liver</td>
<td>0.15</td>
</tr>
<tr>
<td>Pancreas</td>
<td>0.5</td>
</tr>
<tr>
<td>Stomach</td>
<td>1.1</td>
</tr>
<tr>
<td>Heart</td>
<td>0.5</td>
</tr>
<tr>
<td>Lung</td>
<td>0.85</td>
</tr>
<tr>
<td>Esophagus</td>
<td>0.3</td>
</tr>
<tr>
<td>Thyroid</td>
<td>0.08</td>
</tr>
<tr>
<td>Brain</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Risk per organ = Total(\( H_{T} \)) \times r_{T}**

**Neutron equivalent dose**

**Risk of developing a fatal secondary**

**Risk coefficients (NCRP 116)**

**LIMITATION OF EXPOSURE TO IONIZING RADIATION**

**Table 2.** Risk coefficients of developing fatal secondary malignancies by organ obtained from ICRP116 [11].
The results of fatal secondary cancer risk for different studied organs are mentioned in the Figure 2:

✓ Colon and stomach have the maximum risk of secondary cancer risk of 0.041 and 0.040% respectively.

✓ The minimum risk is 0.02 in thyroid organ, the total risk is 0.24%.

**Figure 2**: The percent calculated fatal secondary cancer risk due to photo-neutrons for the various organs.
III. Results and discussion

III.1. Neutron equivalent dose at different patient’s organs

III.2. Risk of developing a secondary cancer

III.3. Sensitivity analysis

➢ **Reference case**: we kept the same geometry as it was in the initial one (without the perturbation).

➢ **Perturbation cases**: remove the corresponding key component.

➢ **Case 1**: Primary Collimator (PC),

➢ **Case 2**: Flattening Filter (FF),

➢ **Case 3**: Multi Leaf Collimators (MLC),

➢ **Case 4**: Jaws (JS),

➢ **Case 5**: Shielding walls (WR).

The neutron equivalent dose was calculated for each case and then compared with the reference model (Ref) that corresponds to the simulation with all parts of the head accelerator.
✓ The equivalent dose is found to be more sensitive to FF component and the maximum difference achieved is 49% in the uterus organ.

✓ The adjacent organs situated in the pelvic and abdominal region are more sensitive to FF, PC, SC and MLC respectively with a maximum differences of 49%, 38%, 26% and 25% achieved in uterus, spleen, spleen, pancreas, respectively

✓ The organs situated at a distance from the treatment field, are more sensitive to shielding walls with a maximum difference achieved of 45% in the brain.

**Figure 3.** Effects of each component on neutron equivalent dose (Eq. dose) at considered patient's organs.
IV. Conclusion and perspectives

➢ As expected, the photo-neutron equivalent dose varies mainly according to the proximity of the organ considered to the target volume.

➢ The equivalent dose of photo-neutrons changed when removing a LINAC specific component and the shielding room.

➢ The equivalent dose of photo-neutrons is more sensitive to FF components of the LINAC for the nearest organs to the irradiation field. Whereas the equivalent dose is more sensitive to the shielding walls of the treatment room for the farthest organs.

➢ It was found that the colon and stomach present the maximum risk of secondary cancer.

➢ In perspective, this study will be enhanced using a more accurate human model phantom, and more effort should be focused on the way to decrease this photo-neutron composition with the purpose of reducing the risk of fatal secondary malignancy.
THANK YOU FOR YOUR ATTENTION