Neutron dose equivalent increase due to range shifter in active proton therapy

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Purpose: Targets located superficially in the body often require a range shifter (RS) when treated with protons to bring the energies in the necessary energy range. The addition of this beamline element increases the neutron production during irradiation which may be a concern in some cases. The aim of the present work is to estimate the increase of neutron dose equivalent in the patient when using the RS. Clinically-relevant positions of the RS were considered.

Material and Methods: A simple geometry was used for Monte Carlo simulations using the MCNP 6.2 code. A SOBP was created to cover a target volume of 15 × 10 × 4 cm^3 at a depth of 4 cm inside a water phantom. This field was considered to mimic a typical field for Hodgkin's lymphoma patients. The RS (Lexan, 3.1 cm physical thickness) was placed between two positions representing the maximum and a typical airgap to the patient surface: 17.4 cm (RS1) and 29.9 cm (RS2). The configuration with no RS was also considered for reference. Neutron spectrum and dose equivalent were evaluated in selected points around the target, in lines at 0º, 45º and 90º from beam direction (figure 1), at distances up to 59 cm from isocenter.

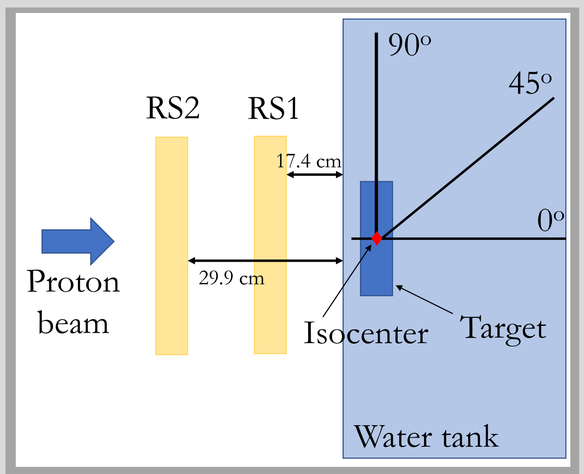

Fig. 1. Sketch of geometry in MC simulation (not in scale). Lines (at 0º, 45º and 90º from beam direction) inside tank represents directions where neutron spectrum and dose equivalent were evaluated.

Results:

Neutron fluence

Effect of RS relevant in regions lateral to target.

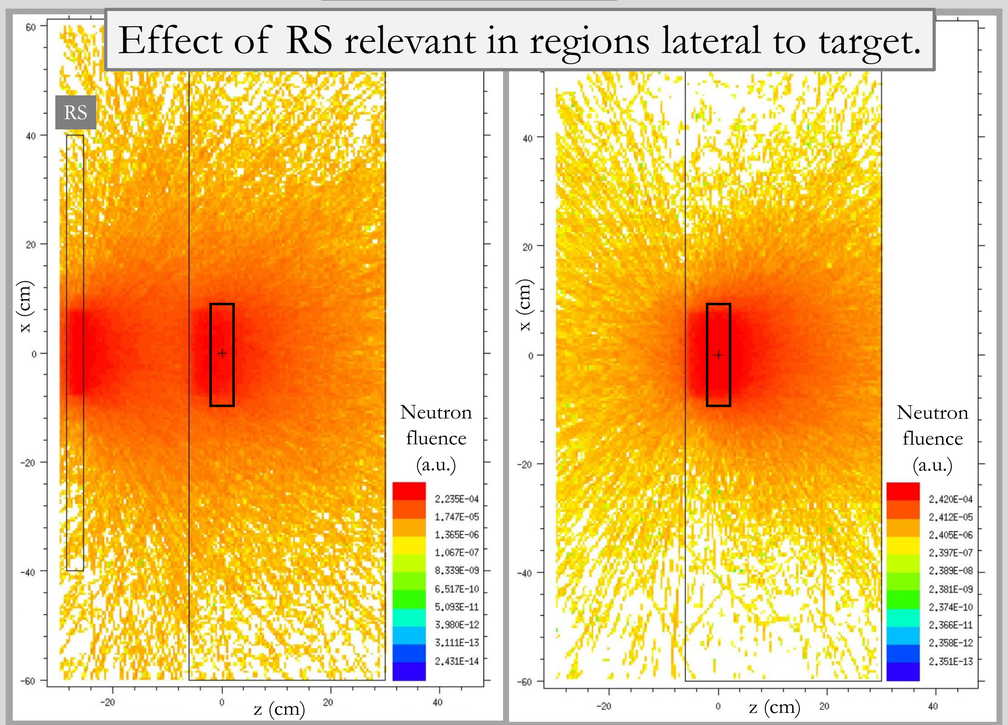

Fig. 2. Comparison of fluence distribution of neutrons (E>0.1 MeV) with and without RS.

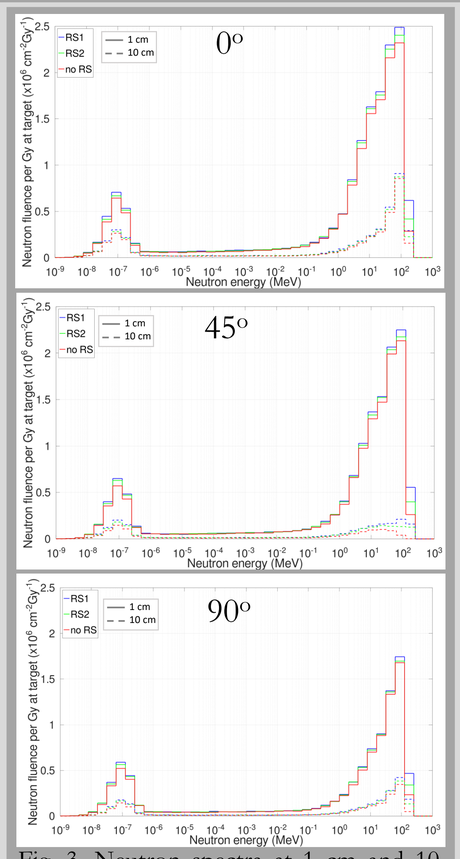

Fig. 3. Neutron spectra at 1 cm and 10 cm from field edge at 0º, 45º and 90º for the three configurations.

- Similar energy distribution in each position for the three configurations at 0º.
- The higher the angle with beam direction, the greater the contribution of fast+high-energy neutrons using the RS, especially when moving further form the target.

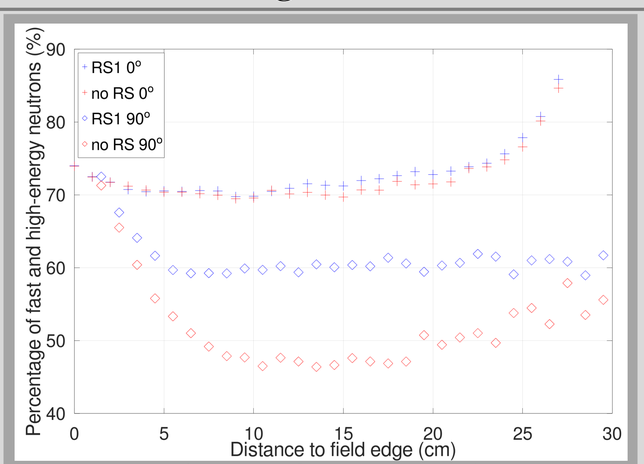

Fig. 4. Contribution of neutrons with an energy higher than 0.1 MeV in each position for the configuration with (RS1) and without RS at 0º and 90º.

Neutron dose equivalent

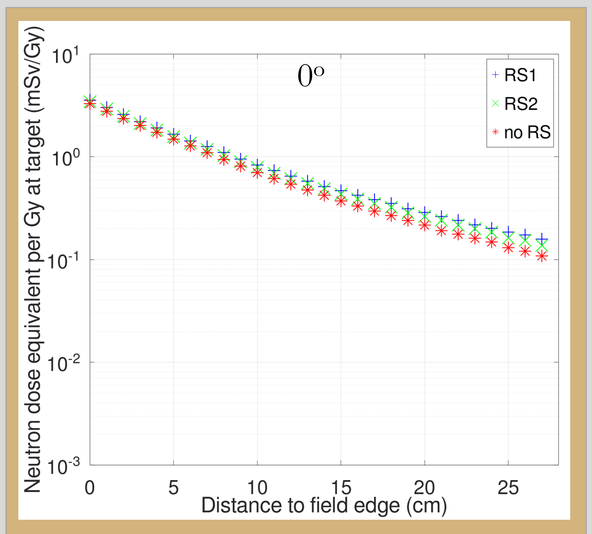

Fig. 5. Neutron dose equivalent per Gy at isocenter at 0º for the three configurations.

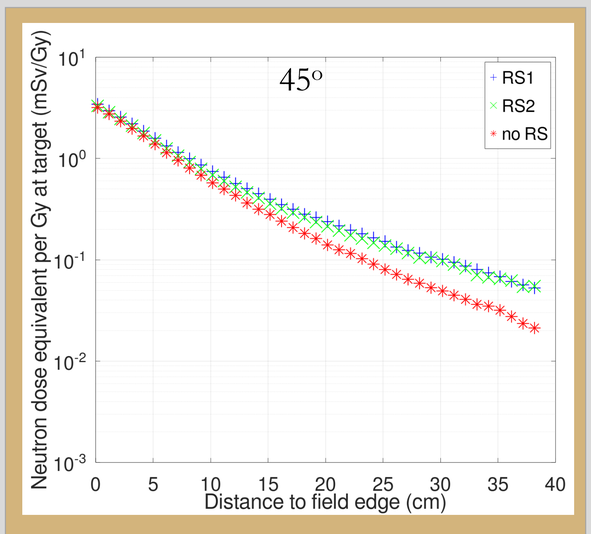

Fig. 6. Neutron dose equivalent per Gy at isocenter at 45º for the three configurations.

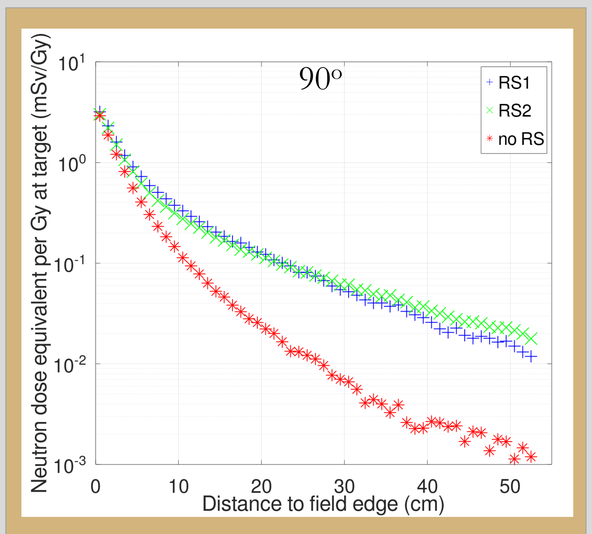

Fig. 7. Neutron dose equivalent per Gy at isocenter at 90º for the three configurations.

- Higher neutron dose equivalent with RS.
- This increase is higher at higher angle with beam direction.
- In general, the closer the RS to water tank, the higher dose equivalent. However, laterally to target, opposite effect is shown at distances over 25 cm from field edge.

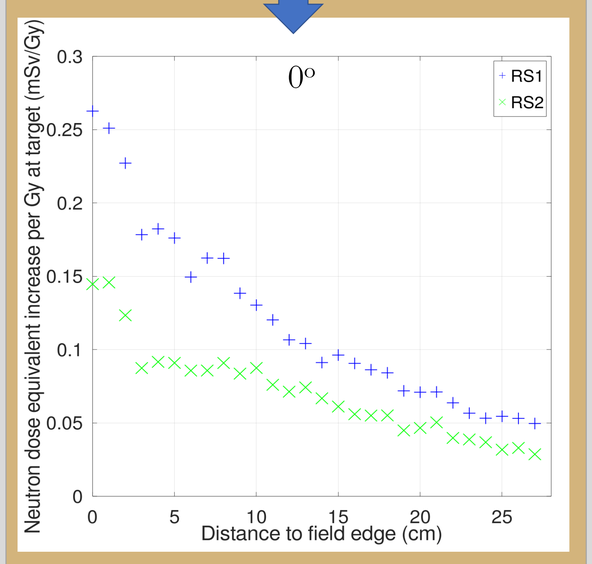

Fig. 8. Neutron dose equivalent increase per Gy at isocenter at 0º for the RS configurations.

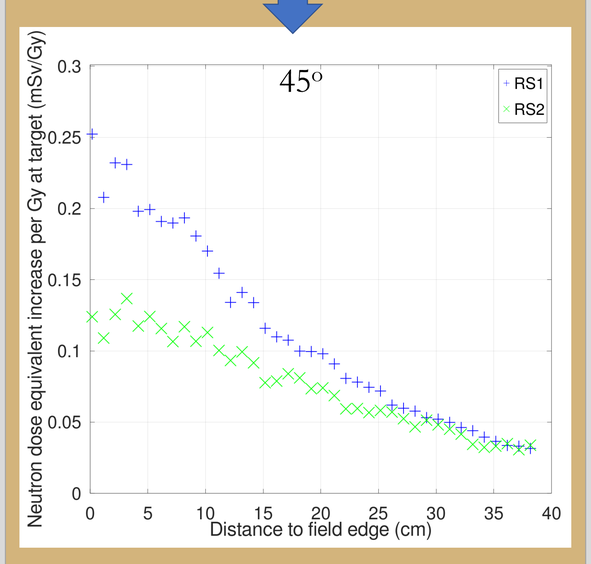

Fig. 9. Neutron dose equivalent increase per Gy at isocenter at 45º for the RS configurations.

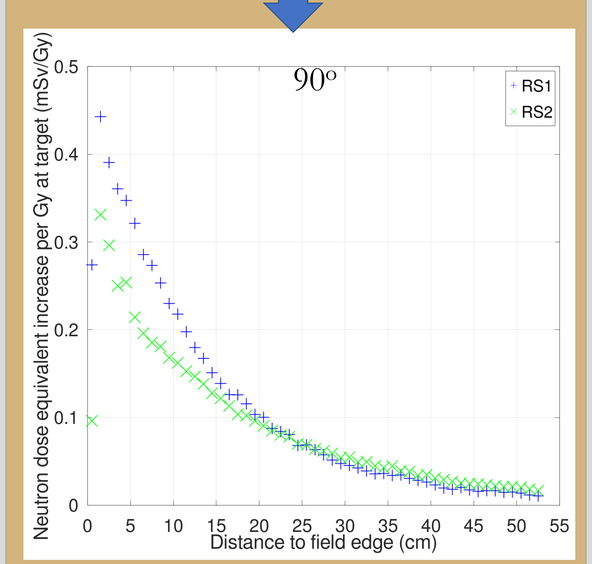

Fig. 10. Neutron dose equivalent increase per Gy at isocenter at 90º for the RS configurations.

Conclusions: RS represents a second neutron source that contributes to an increase in dose equivalent, especially in positions lateral to the target regarding beam direction. Dose equivalent can be up to 0.44 mSv (RS1) and 0.33 mSv (RS2) higher than that obtained during irradiation without RS. At 10 cm from field edge, the increase is reduced between 0.13 and 0.22 mSv (RS1) and between 0.16 and 0.08 mSv (RS2) depending on the orientation with target. Values are dependent on target geometry.

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