Estimating the relative biological effectiveness of neutron radiation for inducing clustered DNA damage via Monte Carlo simulation of direct and indirect action

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INTRODUCTION

- Neutron radiation poses an energy-dependent risk of inducing stochastic biological effects in the human body [1, 2].
- Previous Monte Carlo studies have linked this energy dependence with the relative biological effectiveness (RBE) of neutrons to induce difficult-to-repair clusters of damage in nuclear DNA [3, 4].
- However, these studies have only modeled direct radiation action due to neutrons.
- Thus, a study modeling the damaging effects of neutron indirect action is outstanding.

OBJECTIVES

- Quantify the damage contribution of indirect action in irradiated nuclear DNA.
- Estimate neutron RBE for inducing clusters of DNA damage due to the combined effects of direct and indirect action.

METHODS

- Used the TOPAS extensions framework [5] to adapt a published model for indirect action [6, 7] into our simulation pipeline [3].
- Simulated irradiations of monoenergetic neutrons and X-rays on our custom nuclear DNA model [3] to obtain data on DNA lesions and damage clusters.
- Compared the DNA damage inflicted by neutrons and X-rays to estimate neutron RBE for inducing DNA damage clusters.

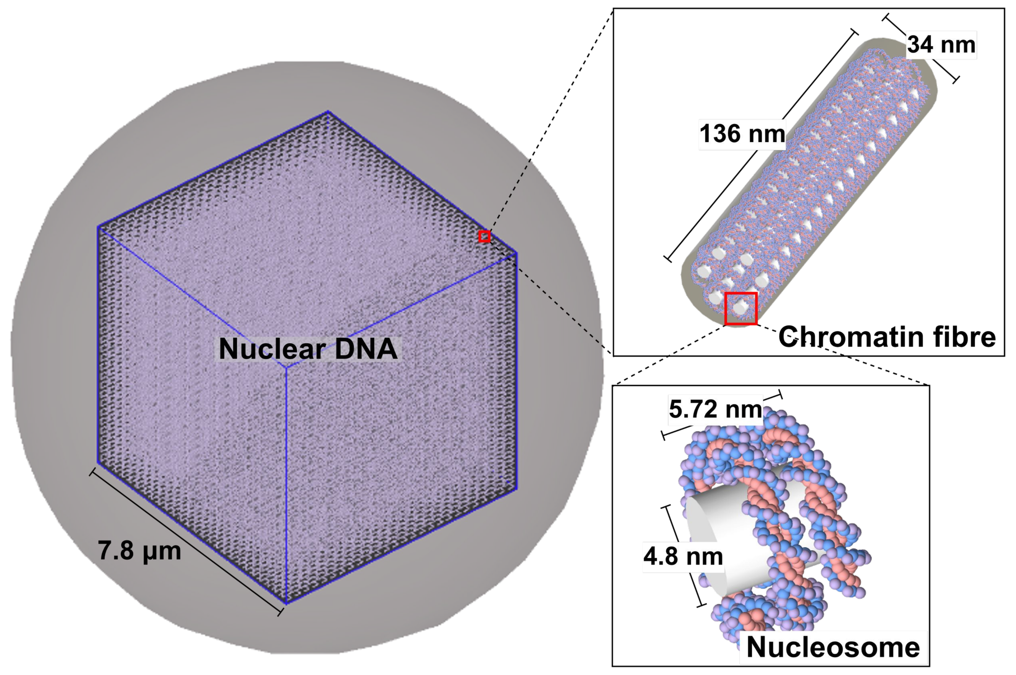
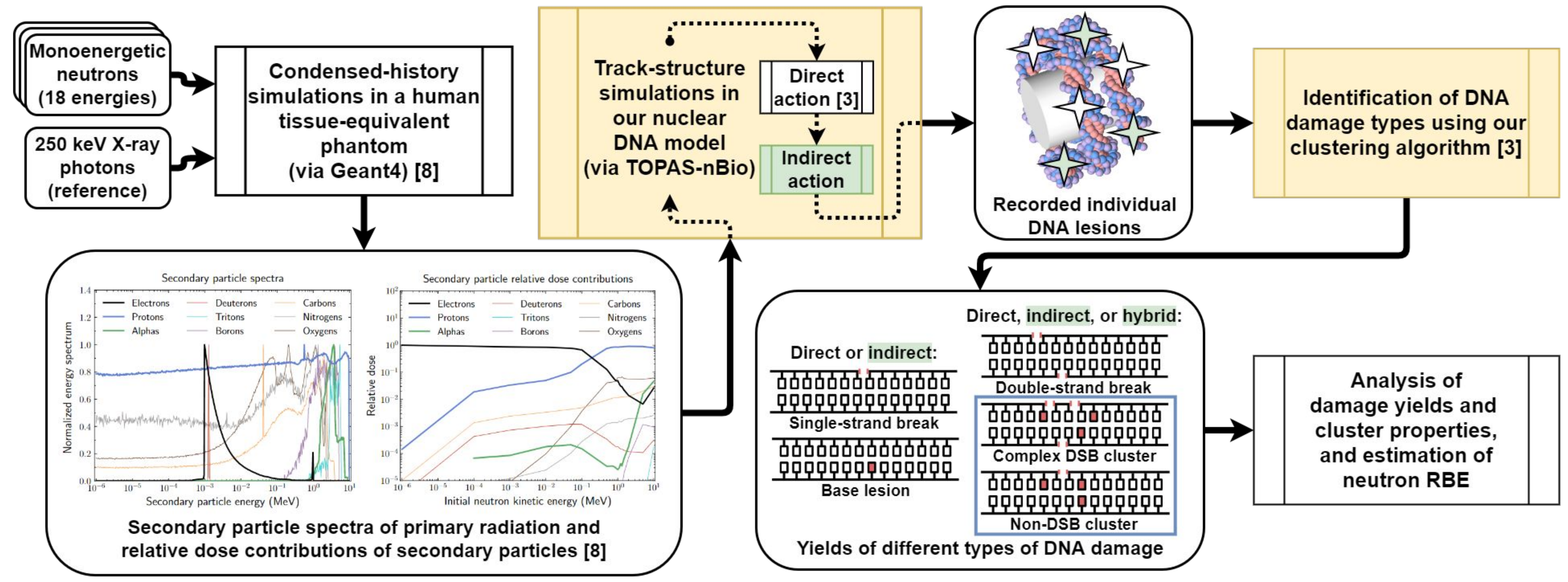


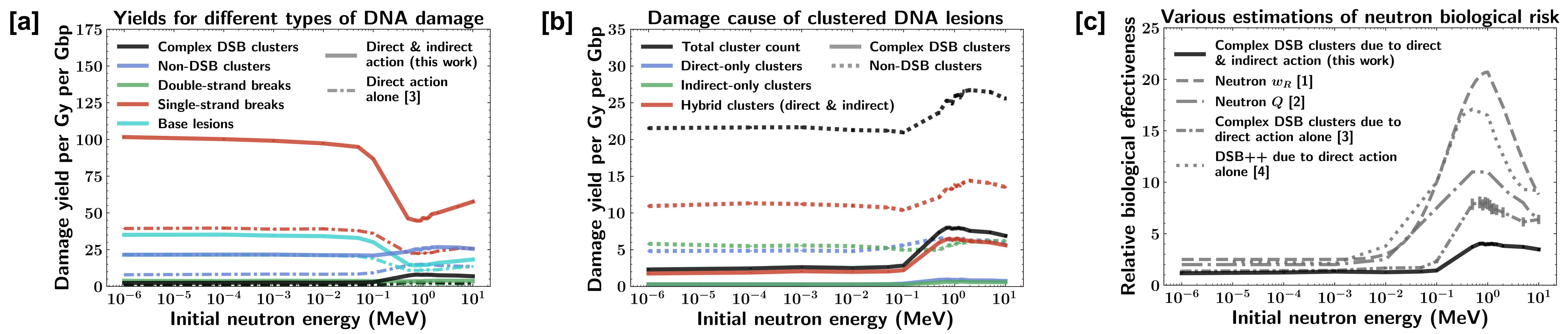
Figure 1: Our full cell model (with custom nuclear DNA [3]) integrated in our simulation pipeline.

Figure 2: Our updated simulation pipeline. The components of the pipeline that were updated for this work are indicated in yellow. Lesions related to indirect action are indicated in green. The two types of DNA damage clusters investigated are inside the blue box.



RESULTS

- **Result [a]**: including indirect action significantly increased the yield of DNA damage (increase varies with damage type). The average cluster length and lesion count per cluster also increased (~50% and ~25%, respectively).
- **Result [b]**: most DNA damage clusters are hybrid in nature (contain lesions due to both direct and indirect action).
- **Result [c]**: our estimated energy-dependent neutron RBE follows similar trends as radiation protection factors [1, 2] and previous direct-action-only estimates [3, 4], but is lower in magnitude.



CONCLUSIONS

- Indirect action has significant effects on radiation-induced DNA damage clusters and serves to amplify the effects of direct action.
- The energy-dependent risk of neutron-induced stochastic effects is likely related to, but not completely explained by, the induction of DNA damage clusters.
- Therefore, the investigation of factors such as DNA damage repair and non-targeted radiation effects is recommended.

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