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Neutron energy effects on asteroid deflection☆

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Whether in the near or distant future, it is inevitable that a hazardous asteroid will eventually enter a collision course with Earth. For large or short-warning-time asteroids, a nuclear device is one of humanity's only technologies capable of mitigating this threat via deflection. A nuclear explosion can deliver truly substantial amounts of energy to irradiate an asteroid body, which makes a nuclear device both highly effective and mass-efficient in practical deflection scenarios. While the outputs and effects of nuclear bursts are well-characterized from the history of nuclear testing, determination of the optimal output spectrum for asteroid mitigation remains an open question.

This work examined how the output neutron energy from a nuclear device standoff detonation affects the deflection of a notional asteroid. Neutrons were prioritized for study over x-rays and gamma rays because neutrons are generally the most penetrative and therefore the most effective source type for

☆Of the overall work described in this abstract, some of the early preliminary effort was submitted to, and presented in, the 2020 IEEE Aerospace Conference in Big Sky, MT, USA, under the same title [1]. A finalized research manuscript, titled "Impact of neutron energy on asteroid deflection performance," was submitted to *Acta Astronautica* on 10 October 2020 for publication consideration.

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deflection. Neutrons can melt and ablate greater amounts of asteroid surface material, increasing the amount and speed of blow-off debris, resulting in a greater momentum impulse and velocity change in the asteroid body. The hypothesized asteroid in this work was Apophis-sized, 300 meters in diameter, and composed of silicon dioxide at a bulk density of 1.855 g/cm^3 due to a porosity of 0.30. This object was intended to be a reasonable, representative type of asteroid that might require a nuclear device for successful deflection in a shortened timeframe.

14.1 MeV fusion and 1 MeV fission neutron energy sources were separately modeled in MCNP to quantify their distinct energy depositions in the asteroid target. A unique discretization methodology was developed to efficiently tally the energy deposition spatially across the asteroid's region of irradiation. The asteroid was discretized in angle by tracing the rays emanating from the point of detonation and in depth by considering the neutron mean-free-paths. This high-fidelity approach was shown to deviate from previous analytic approximations commonly used for asteroid energy deposition.

50 kt and 1 Mt neutron yields of the energy deposition mappings were imported into a hydrodynamic asteroid model in ALE3D to simulate the deflective response due to blow-off ejecta. Under-explored in literature, changing the neutron energy was found to have up to a 70% impact on deflection performance for the higher yields and depositions, a result of the induced differences in the energy deposition profiles and in the energy coupling efficiencies. Accounting for secondary particles, especially capture gamma rays, significantly altered the profiles and couplings. For the lower neutron yields and depositions, however, the importance of the neutron particle energy diminished: less-intense irradiations resulted in nearly-equal asteroid deflection velocities between the 14.1 MeV and 1 MeV sources. The magnitude of energy deposition accounted for most of the observed variation in the asteroid velocity change, making the coupling efficiency more significant than the spatial profile characteristics.

These findings are vital for determining the optimal source neutron energy spectrum for asteroid deflection applications.

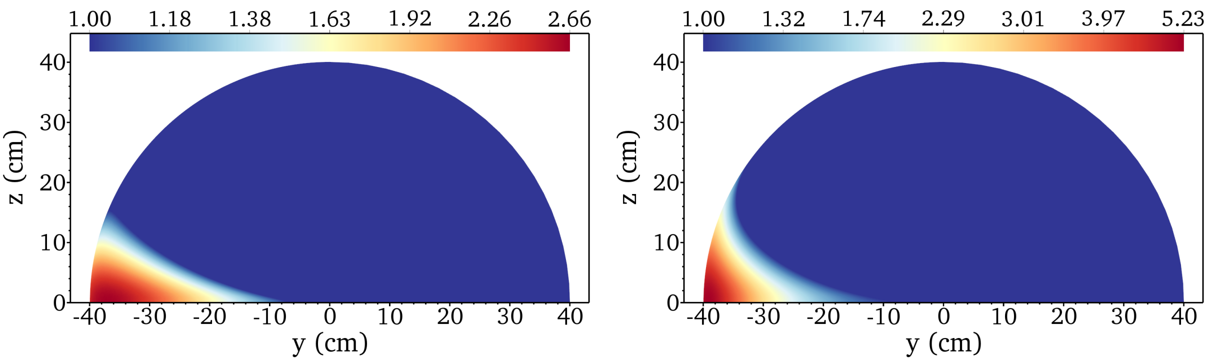

Figure 1: Asteroidal energy deposition heatmaps generated from a standoff 50 kt yield of 14.1 MeV (left) and 1 MeV (right) neutrons, visualized on a small 0.8 m asteroid to enlarge the area of the deposition region and better visualize the heating gradients. The colorbars are logarithmically scaled, plotting the dimensionless quantity E_{dep}/E_{melt}, where E_{dep} is the energy deposition at a given location in J/g and E_{melt} is the 1941 J/g melt threshold for SiO_2. Areas with colors other than dark blue are melted. The 14.1 MeV neutrons (left) heat parts of the asteroid to 2.66 times above the melt threshold for SiO_2, while the 1 MeV neutrons (right) push to 5.23 times beyond the melt minimum. With ground zero (GZ) located here at coordinates $(-40, 0)$ cm, the maximum melt depth for the 14.1 MeV neutrons (left) is about 33 cm beneath GZ and $\sim$31 cm for the 1 MeV source (right). The 1 MeV neutrons (right) melt a much greater fraction of the 45° irradiated surface area, with material along the curved outer surface as far as 34° away from GZ reaching the 1941 J/g threshold, compared to only $\sim 21^\circ$ from the 14.1 MeV neutrons (left). All of these differences in energy deposition between the two neutron energies can affect the resulting asteroid deflection.

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Comments:

Abstract for a potential oral presentation time slot; thank you for your consideration.

References

[1] L. S. Horan IV, D. E. Holland, M. Bruck Syal, J. Wasem, M. L. Dexter, J. E. Bevins, Neutron Energy Effects on Asteroid Deflection, 2020 IEEE Aerospace Conference (2020).