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STAND-OFF NUCLEAR DEFLECTION:
THE IMPORTANCE OF SHAPE, COMPOSITION AND SPECTRUM

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Objects on an Earth-impact trajectory can be diverted using nuclear devices, where energy is deposited in the form of x-rays, gamma rays, and neutrons, and the resulting blow-off of the superheated material deflects the remaining object. The details of the device spectrum, placement of the device and composition of the target heavily influence the deflection outcome. Numerical simulations provide a means for estimating deflections in a variety of scenarios. This modeling requires a detailed understanding of the device spectrum, how that energy couples to the material, the response of the material, and the numerical accuracy of the simulation. Improper treatment of any of these components can lead to large inaccuracies. In this talk, we address how to model asteroid deflection with a nuclear device. This includes a discussion on the relative importance and effectiveness of different nuclear energy types, how that energy couples to various asteroid compositions, sizes and shapes, the prompt material response, and computational approximations that can be made to improve efficiency and accuracy.

First, to understand the relative importance of the spectral components, we explore the energy coupling efficiencies for monochromatic and thermal distributions of x-rays, mono-energetic neutrons, and nuclear device neutron spectra[1] in a variety of asteroid and comet-like compositions. We find that neutrons and hard x-rays are most effective at penetrating,
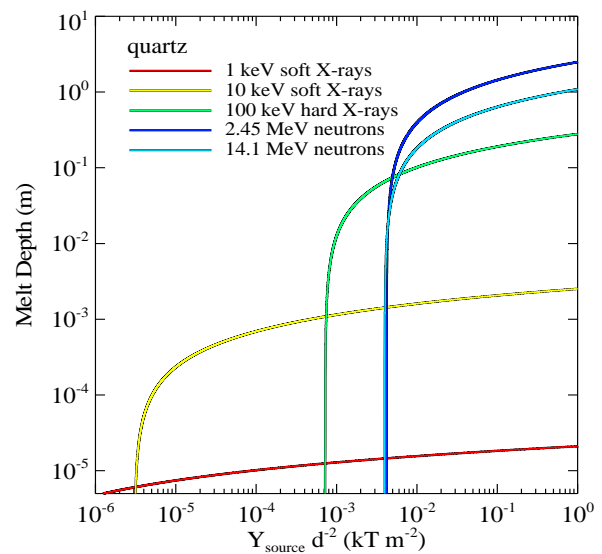

Fig 1. Estimate of the melt depth for different energy sources in SiO_2 as a function of source yield and stand-off distance. The more material melted/vaporized, the larger the push from the initial blow-off

melting and vaporizing material. But real outputs representative of tested devices show that the dominant energy released is in the form of thermal/soft x-rays. Soft x-rays, in contrast to hard x-rays and neutrons, have shallower penetration depths in asteroid and comet-like materials, such that at equivalent fluxes (sufficient to melt/vaporize material), soft x-rays heat less mass to higher temperatures, resulting in a larger fraction of deposited energy being re-radiated away. These two effects (the decrease in the amount of mass

affected and the increase in the energy lost) can lead to smaller deflection impulses applied to the body.
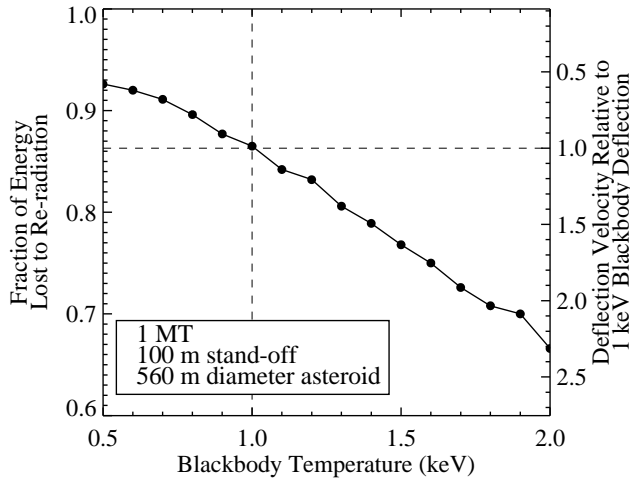

Fig 2. Fraction of energy re-radiated away and resulting deflection velocity resulting from 1MT source at 100 m incident on a 560 meter diameter SiO_2 spherical body as a function of blackbody temperature.

Using a range of spectra dominated by soft x-rays that span the space of realistic outputs, we determine the prompt speed change induced by vaporized surface material due to a stand-off nuclear explosion in a variety of asteroid shapes, compositions, densities and sizes. We use this as a lower limit on the deflection velocity to avoid the uncertainty associated with additional ejecta that is strongly a function of the internal composition of the body. We explore stand-off bursts at distances ranging from 50 meters to 1 kilometer on spherical and elliptical objects, some with craters and/or surface boulders. For the spherical, featureless systems, it is shown that the deflection impulse given to the body depends significantly on the x-ray spectrum, and less so on the yield of the device, whose flux can be easily moderated by changing the height of burst.
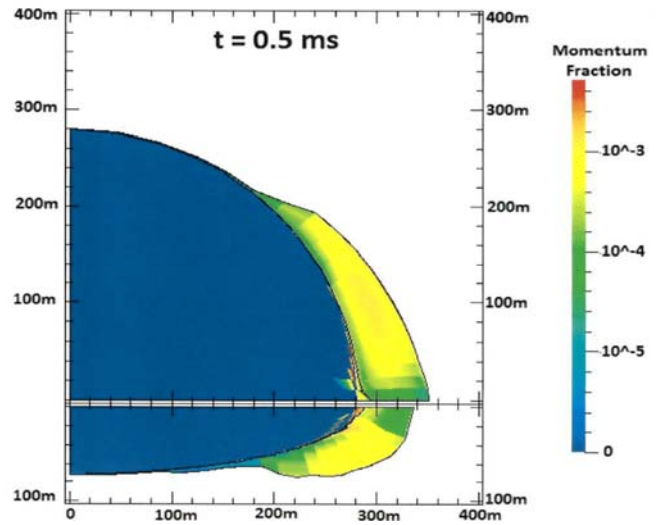

Fig 3. Blow-off momentum of a 560 meter diameter spherical asteroid compared to an elliptical asteroid at 0.5 ms. The elliptical asteroid receives a smaller push in part due to the smaller surface area exposed.

In addition to the device and compositional sensitivities, we explore the limits of simulation accuracy and develop methods to increase our computational efficiency by mapping 1D results onto arbitrary 2D and 3D geometries. We also develop an analytic approximation that provides a good estimate for the deflection velocity in most cases. These results are used to estimate the best standoff distance to maximize melted/vaporized material as a function of device and compositional variables.
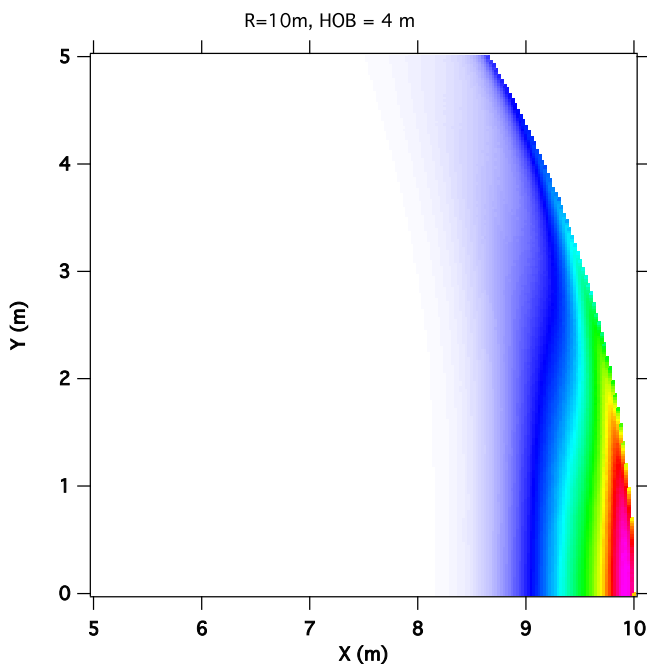
R=10m, HOB = 4 m

Fig 4. Example of mapping 1D energy deposition profiles for a 2.45 MeV neutron source at a stand-off distance of 4 meters onto a 20 meter diameter 2D SiO₂ object. This 1D to 2D mapping reduces the computational time by two orders of magnitude.

[1] Glasstone, S. & Dolan, P., The Effects of Nuclear Weapons, Washington DC: U.S. Dept. of Defense, 1977.