Initial Parameter Study of the Response of Simple Asteroid or Cometary Nuclei Models to a Nuclear Burst

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There is much popular press about Potentially Hazardous Objects (PHOs) and how to mitigate their threat. The two mitigation options are destruction or deflection of the PHO. Presently, the most technically feasible method of deflection is a nuclear stand-off burst [1]. However, many questions remain as to the response of an asteroid or comet to a nuclear burst. Recent increases in computing power and scientific understanding of the physical properties of asteroids and comets make it possible to numerically simulate the response of these porous and inhomogeneous bodies to strong shocks and radiation. Here we use the radiation-hydrocode RAGE to explore the coupling of radiation energy from a nuclear burst to a grid of simplified PHO models. We use simple 2-D axisymmetric models of 100 m diameter spherical PHOs composed of different materials to study their response to nuclear bursts of 10, 100, and 1000 kt with distances of 20 and 70 m.

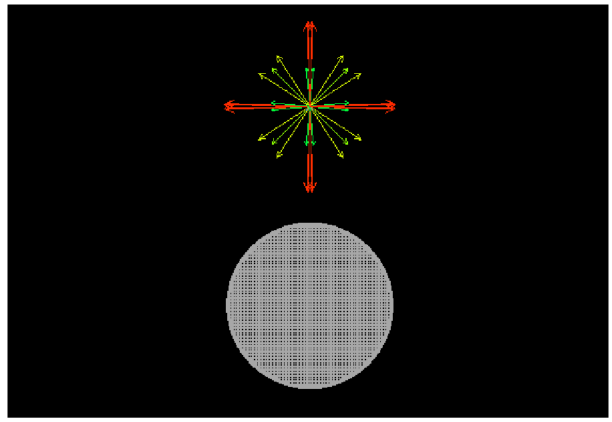

Figure 1: Initial configuration of the 100 meter target and nuclear munition (small dot)

Background

The NASA 2007 white paper "Near-Earth Object Survey and Deflection Analysis of Alternatives" [1] affirms deflection as the safest and most effective means of PHO impact prevention. Of the possible deflection mechanisms, nuclear munitions are by far the most efficient in terms of yield per unit mass launched and are technically mature. However, there are still significant questions about the response of a cometary nucleus or asteroid to a nuclear burst. Previous calculations of deflection by nuclear munitions ([2], [3], [4], [5], and [6]) either do not assume a standoff burst and/or do not account for the substantial porosity or internal composition or structure variations. These properties may substantially affect how a PHO responds to a standoff nuclear burst [7]. Several recent rendezvous and flyby missions to asteroids and cometary nuclei show their wide range of structure and composition, allowing us to model them better. In addition, we now have available computer codes that allow us to model the response of a simulated PHO to the energy from a nuclear burst.

Model Parameters

We use the RAGE radiation-hydrodynamics code [8] with radiation transport. For our initial studies, we use a fiducial 100 meter spherical target that is of uniform composition. We use these simplified models to establish the ideal case of solid body response and to provide a reference point for subsequent more physically realistic studies. Also, the simple models can be compared at least in part to analytic models and/or scaling relations to provide a validation check on our simulations.

We examine basalt, iron, water ice, and carbon (graphite). The water ice and graphite compositions are meant to bound the composition of cometary nuclei and carbonaceous chondrites, while the iron and basalt compositions are similar to that of many asteroids. Although a real PHO will have material strength, we neglect it for this exercise. We do not model the nuclear munition in detail. To simulate the nuclear burst, the energy is sourced into a small aluminum sphere over an arbitrary, but short (5 μsec) time interval. This "device" is 20 or 70 meters away from the near surface of the target, where 20 m is the optimum standoff distance according to [2]. Because RAGE is not set up to handle a true vacuum, we use a low density ($\sim 3 \times 10^{-8}$ g/cm^3) solar wind composition gas for the background. In Figure 1, we show the initial configuration of the target and munition. We run the calculations to 0.1 seconds to obtain initial estimates of the ablated material and the deflection velocity imparted to the target.

Table 1: Center of mass velocities for targets

material	Density	Target Distance	10 kt	100 kt
	(g/cm^3)	(m)	(cm/s)	(cm/s)
Water ice	0.998	20	80.9	577
graphite	2.25	20	7.2	206
basalt	2.868	20	7.6	192
basalt	2.868	70	1.7	19.7
iron	7.85	20	2.6	95.6

Table 2: Energy absorbed by targets from a nuclear burst

material	Target Distance	10 kt	100 kt
	(m)	($\times 10^{20}$ erg)	($\times 10^{20}$ erg)
Water ice	20	0.65	5.76
graphite	20	0.66	5.97
basalt	20	0.64	5.47
iron	20	0.63	5.50

Preliminary Results

Here, we present results for 100 meter spheres of water ice, for yields of 10 kt, 100 kt, and 1000 kt. In Table 1, we show show the imparted center of mass velocity to PHO models of differing compositions. From [2], moving a PHO by one Earth radius requires a velocity deflection of $\sim 7/t$ cm/s (where t is in years). This velocity deflection involves either accelerating or retarding the orbital motion. Our 20 cm/s deflection (for a basalt sphere 70 m from the burst) would be adequate for a lead-time as short as 4 to 5 months. Moving the burst to only 20 m from the PHO makes it even more effective, as the velocity increases to 190 cm/s. Note that this velocity ratio ($19.7/192 = 0.102$) is almost exactly the ratio we expect from the $1/r^2$ effect ($20^2/70^2$) of 0.082. A burst of 1000 kt only 20 m from the target shows significant disruption of the target by 0.1 s and such a burst would not be suitable for deflection. The worst case occurs for deflecting an iron PHO with a 10 kt burst, but even there, the lead time is about 4.1 years. If we feel disruption might be a problem in real life, we could use several nuclear devices to impart several less energetic pushes on the PHO.

A 10 kt burst has an energy of 4.18×10^{20} ergs, and from geometric considerations, we expect that about 25% of the energy from the device will reach the PHO model 20 m away. Thus, about 10^{20} ergs will reach the asteroid. To determine the energy absorbed by the PHO, we need the absorption coefficient of the material in question. Instead of analytically computing the absorption coefficient (which would be temperature and density dependent), we analyze our RAGE results to determine the amount of energy absorbed by the PHO model. Our results (shown in Table 2) show a small difference ($\sim 10\%$) on the amount of energy absorbed due to compositional differences. The PHO model absorbs about 12 to 16% of the total energy emitted by the nuclear munition. Thus, the PHO model absorbs about half of the energy incident upon the surface.

Even with our simplified models, we see that bursts of about 10 kt will be effective in deflecting a 100 m diameter solid PHO away from Earth if the lead time is about 1 to 4 years. Assuming there is no issue with fragmentation, our calculations of a 100 kt burst 20 m from a target PHO show that it is capable of deflecting a PHO with no more than 4 months of lead time. We will need to run similar calculations for PHO models that have a realistic shape, composition, rotation rate, strength, and porosity for ”playbook” entries (see Plesko et al. this conference).

References

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