ON NUKING MENACING ASTEROIDS

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Introduction: Most scientists now accept that impacts on the earth of large asteroids and comets have occurred in the past, and will, without intervention, occur again; with devastating affects on the earth and all living creatures. About ten years ago, researchers [1,2] and others studied a number of ways that an asteroid could be diverted from an impending collision with the earth by pushing it sufficiently to change its course, making it miss the earth. Among the methods suggested, it is generally accepted that with a short warning time, such as a few years, only the nuclear bomb approach would work.

In [3] I report some recent studies on these issues, including the effect of asteroid porosity which is now thought to be likely. One of the conclusions is that porosity can make the use of surface explosives or impacts of large masses, both methods that deflect by cratering, ineffective. Of the other cases, some of the more interesting conclusions deal with the mitigation methods using a standoff nuclear weapon, which I present here.

Deflection by standoff nuclear detonations: The standoff method uses a nuclear weapon detonated at some height above the asteroid surface, resulting in a large deposition of x-ray or neutron energy into a surface layer of the asteroid. The neutrons penetrate further so generally give more effect than the x-rays. Therefore I assume a weapon designed for a significant neutron yield. Both [1] and [2] consider this method. Both obtain estimates of the impulse imparted to the asteroid by estimating a blow-off velocity and a total blow-off mass. A more precise result is obtained by an analysis of the wave dynamics of the processes, which I obtained using a one-dimensional wave propagation code and the ANEOS three phase equation of state for the response of the asteroid material.

I consider both porous and non-porous materials. I use the ANEOS model for Quartz given in [5]. For the porous case, the Herrmann p-alpha model is added to the underlying EOS for quartz. The p-alpha model is characterized by three material properties. The distension ratio α is the porous mass density divided by the mass density of the particulate solid material. The pressure P_e is a pressure at which crush begins, and P_s the pressure at which all voids are crushed out. There is a curve of distension *v.* pressure defined by these three parameters. To account for phase changes, I assumed that the crush pressure becomes zero in any melt or vapor state.

I assume that the energy from the detonation is instantaneously deposited into a uniform 20 cm thick layer. That creates a very hot high-pressure layer of material whose initial temperature and pressure are determined by the equation of state and, for the porous case, the p-alpha model. The interior material begins in its near-zero pressure, low temperature ambient state.

For a non-porous asteroid, the initial hot state is at the original mass density of 2.65 g/cm^3; and, if the initial specific energy is greater than about 2.5 MJ/kg, is in the melt regime. That initial state creates a compression wave that moves into the interior with a magnitude of about 1/2 of the initial pressure. An unloading wave proceeds into the hot layer both from its front free surface and from the interface at the cold interior, unloading the material in the hot layer adiabatically back to a zero pressure as it "blows-off". In that process the thermodynamic states enter the vapor dome, and become a mixture of melt and vapor. The code calculates the detailed history of these complex processes. The momentum per unit area imparted to the asteroid can be determined by integrating the pressure history at the interface.

For the porous case I assume an initial porous mass density of 1.325 g/cm^3, so the initial distension is 2. There are three different cases of interest, depending on the magnitude of the initial specific energy in the heated layer, which is determined by the weapon yield and the standoff distance. If the specific energy is below the melt energy the hot layer remains solid. That is the case favored in [1]. However, for the porous material, the Gpa-level pressure in the solids is well above the crush pressures and the solid particles expand into the void spaces to the Mpa-level pressure consistent with the crush curve. That orders of magnitude reduction in pressure of the hot layer results in there being only a very small transmission of impulse to the asteroid interior.

If the initial specific energy is above 2.6 MJ/kg but below about 10 MJ/kg, the initial state is above melt, so the crush pressure is zero. Then the solid particles expand to entirely fill the porous volume to give an initial state at a mass density of 1.325, and a state entirely within the vapor dome and at very low pressure. Therefore the transmitted pressures are very small, but, since the wave speeds are also very low in this thermodynamic regime, the pressure is maintained for a long time. Code calculations in these cases are very difficult.

The last case of interest, which turns out to be the one of primary interest, has the initial specific energy above 10 MJ/kg at the mass density of 1.325, which is in a melt but not a vapor state. Compared to the non-porous case, the pressure is reduced by the porous expansion by a factor of several, but the wave speeds are also reduced. The net effect is that the porous asteroid obtains less impulse than the non-porous one, but that the difference decreases as the initial specific energy increases to very large values.

The calculated momentum per unit area imparted to the asteroid as a function of the initial specific energy for these cases, for both the porous and non-porous cases, is shown in figure 1, together with the results obtained from the assumptions of the previous studies.

Following the procedure similar to that in [1], this information can be used to determine the total impulse transmitted to a spherical asteroid with various yields and standoff distances. At any point on the surface, the deposition depth is found by assuming that 20 cm is the slant distance along the line of sight from the detonation point. That deposition depth determines the specific energy, which ranges from a maximum just below the detonation point to zero at the angle where the line of sight from the burst point just grazes the asteroid surface. The momentum results then are used to get the contribution to the momentum at each location, and a numerical integration adds up the contributions from all points.

The final results are shown in figure 2 for 100 Kt of deposited neutron energy and a 1 km diameter asteroid. For large standoff distance for the porous case, the transmitted momentum is negligible, but it approaches the non-porous asteroid case as the standoff distance becomes quite small. That is, of course, a consequence of the fact that the specific energies of deposition become much larger at the closer distances. For the non-porous case the maximum momentum is obtained for a standoff distance of only 23 m, and for the porous case of about 15 m, only 5% and 3% of the asteroid radius, respectively. These are much less than the 40% radius value suggested in [1] and the 25% gotten in [2].

The mass of a solid silicate 1 km diameter asteroid is about 1.4 10^{12} kg, so the velocity increment imparted at the optimum distance from this yield is just about 1 cm/s, the value necessary to deflect an asteroid enough to miss the Earth with a decade lead time [1]. The maximum specific energy just under the detonation is about 1.2 10^3 MJ/kg, with an initial temperature of 3.5 10^5 °K (28 ev), and an initial pressure of 1.5 10^3 Gpa. Approximately 35% of the bomb neutron energy is absorbed over only 2.2% of the asteroid surface, on a 300 m diameter circle. The area-averaged deposition depth is 3.25 cm, ranging from 20 cm just under the device to zero at the extremities.

Therefore100 Kt of deposited energy from a detonation height of 23 m would be sufficient to deflect a 1 km solid asteroid with a 7-10 yr lead-time. Less lead-time would require more energy. The porous asteroid would require a little less energy because of its smaller mass, but the device would need to be detonated even closer for maximum effectiveness. Neither case is likely to disrupt the asteroid.

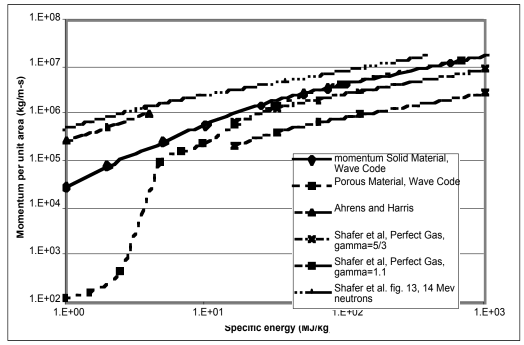

Figure 1. The momentum per unit area imparted for porous and non-porous asteroids as a function of the initial deposited specific energy.

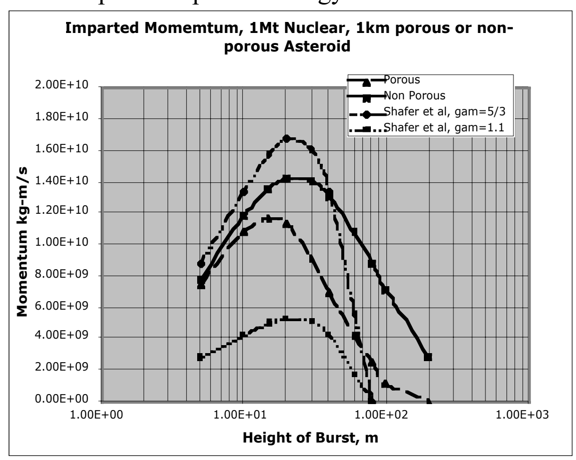

Figure 2. The momentum imparted to 1 km diameter non-porous and porous spherical asteroids by 100 Kt of neutron energy, as a function of the standoff distance.

References: [1] Ahrens T.J. and Harris A.W., (1994) "Deflection and Fragmentation of NEAs" in *Hazards due to comets and asteroids*, ed. by T. Gehrels. pp 897-928.
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[4] Hertel E. S and Kerley G. I. (1998) , "CTH Reference manual: The equation of state package" Sandia report SAND98-0947.