POROSITY CONTROLS ON ASTEROID DEFENSE STRATEGIES. M. Bruck Syal[1], P. H. Schultz[1], D. S. P. Dearborn[2], and R. A. Managan[2], [1]Brown University, Providence, RI 02912 (Megan_Syal@brown.edu), [2]Lawrence Livermore National Laboratory, Livermore, CA 94551

Introduction: Impacts of sufficient energy to cause significant loss of life have occurred throughout Earth's history and will, in the absence of defense measures, occur in the future. Successful mitigation of future Earth-bound impactors will depend on the accuracy with which researchers can predict the target body's response to any defense strategies taken. Here we examine the effects of asteroid porosity on the deflection or disruption of asteroids by standoff nuclear explosions. Although the vast majority of asteroids for which mass and volume information are available are known to be very porous [1], previous work has not fully considered how porosity may affect asteroid response to nuclear bursts. By adding an empirically determined porous crush curve to the equation of state used in numerical modeling of the problem, this study demonstrates how asteroid porosity acts to attenuate shock waves initiated by nuclear energy deposition. This damping effect, which is related to energy expended during the compaction of pore space, has repercussions for the selection of optimal device yields and standoff distances for the deflection of threatening objects.

Background: If an asteroid or comet is found to be on a collision course with Earth, intervention can be achieved by either disruption (fracturing the near-Earth object, or NEO, into many small, harmless pieces) or deflection (imparting a sufficient change in velocity to take the NEO off of an Earth-bound trajectory, while preserving the large-scale structure of the body). A NASA (2007) white paper, "Near-Earth Object Survey and Deflection Analysis of Alternatives," found deflection to be the "safest and most effective means of PHO [potentially hazardous object] impact prevention." Disruption is considered a riskier approach because it would rely heavily on the (highly uncertain) material properties and internal structure of the NEO; a failed attempt to fully disrupt an object may lead to unpredictable trajectories for any remaining large fragments of the initial body. While deflection is the favored approach, it is important to note that, for the shortest warning times, disruption may be the only viable option [2,3].

Although a host of alternative methods to deflect hazardous NEOs have been proposed, including focused solar collectors [4,5,6], mass drivers [4], gravity tractors [7], and pulsed lasers [8], only nuclear explosives [9] and kinetic impactors [10] have been previously tested in space. As such, in the event of a near-future impact, these already-tested technologies would enable a more timely intervention, improving the probability of a successful mission.

Ultimately, a spacecraft would need to safely deliver either the kinetic impactor or nuclear explosive to the threatening NEO. In comparing the energy per unit mass associated with the kinetic and nuclear deflector cargos (50 MJ/kg for kinetic; 4×10^6 MJ/kg for nuclear) the relative cost-efficiency of the nuclear approach is abundantly clear [11]. As the kinetic approach is much less fraught with social and political controversy, it represents a likely option for smaller objects (less than a few hundred meters in diameter), but, beyond this size (or for shorter warning times), transporting a sufficiently large kinetic impactor would exceed the payload capabilities of currently available launch vehicles.

Numerical Approach: While analytical approaches can be utilized to make initial estimates for the deflection imparted by standoff nuclear explosions [3,11], a more rigorous result is obtained by using hydrodynamic codes. Such calculations provide a detailed analysis of both the ejecta blowoff process and the dynamics of shock wave propagation through the body. The latter effect, which is sensitive to NEO strength, density, porosity, and structure, is of critical importance; tracking the response of the object to the shock wave provides essential insight on whether undesirable effects such as large-scale fracturing of the NEO or spallation off of the far side of the body may occur.

We conducted an array of simulations using CALE, a two-dimensional Arbitrary Lagrangian-Eulerian (ALE) hydrodynamics code [12]. CALE is a multiphase, multi-material finite element code developed at Lawrence Livermore National Laboratory over the past 30 years. As many problems of interest have axial symmetry (e.g., spherical and ellipsoidal bodies), and fully three dimensional models are costly in terms of computational time, two-dimensional codes like CALE are well-suited to addressing this problem.

In order to investigate the effect of porosity on an asteroid's response to a standoff nuclear burst, we use a porous material equation of state (EOS) and implement an experimentally determined crush curve for porous limestone. Although data are only available for pressure-density pairs down to a porosity of 0.16, even this modest amount of porosity is adequate for demonstrating the attenuating effects of porous asteroidal material. As limestone is of comparable grain density (2.70 g/cm^3) to the minerals that dominate asteroid reflectance spectra (e.g., pyroxene and olivine), for the purpose of these calculations, it can function as a suitable proxy for asteroidal material.

Simulation of a neutron-rich nuclear device detonation is accomplished by including a time-dependent internal energy source term. The total amount of energy coupled to the asteroid by neutron radiation is calculated separately, using radiative transport models. Using the results of these models, the source term increments the total internal energy deposited into the asteroid surface over a standoff height-dependent area.

Results: All simulations were performed on homogeneous, spherical asteroids with diameters of 270 meters (Apophis-sized), using 60-meter standoff heights. Two compositional end-member cases were used for each standoff yield: limestone with no porosity (ρ = 2.70 g/cm^3) and limestone with 0.16 porosity (ρ = 2.27 g/cm^3). Yields ranged from 0.5 kilotons (kt) to 1.3 Megatons (Mt).

Dramatically different final density distributions and fragment velocities were calculated for the porous (Φ = 0.16) and non-porous (Φ = 0.0) asteroids (see Fig. 1,2). Energy absorption due to the compaction of porous material, even for this moderate amount of porosity, significantly attenuated the shock wave impulse delivered to porous bodies. While this damping effect should help to alleviate the risks of unintentionally fracturing or disrupting an asteroid during deflection attempts, it would likely act as a hindrance to any attempt at fully disrupting an NEO.

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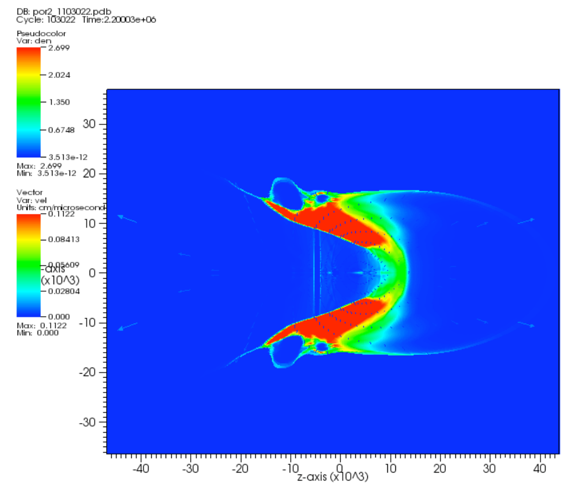

Fig. 1. Density plot (blue = vacuum, red = 2.7 g/cm^3) describing a non-porous (Φ = 0.0), 270-meter asteroid's response to a 1.3 Mt standoff burst (standoff height = 60 m). The body is completely disrupted within 2 seconds after the burst.

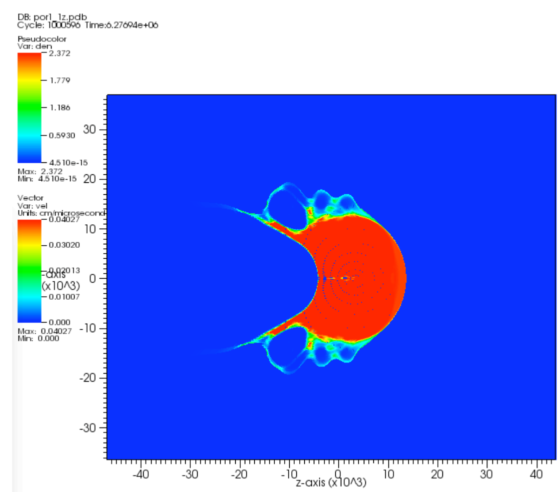

Fig. 2. Density plot (blue = vacuum, red = 2.3 g/cm^3) describing a porous (Φ = 0.16), 270-meter asteroid's response to a 1.3 Mt standoff burst (standoff height = 60 m). The body, plotted here at 6.3 seconds after the burst, maintains large-scale structural integrity.