Energy Deposition in an Asteroid-like Target from a Stand-Off Nuclear Burst

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Large asteroid and comet impacts on Earth are rare yet preventable natural disasters. There are many outstanding questions about how to prevent an impact once a hazardous object is found. Nuclear munitions are currently thought to be the most efficient and technologically feasible method of delivering an impact-preventing impulse to a PHO. However, there are still major uncertainties about the response of PHOs to a nuclear burst and the most effective and safest ways to use nuclear munitions for impact hazard mitigation.

Background

The Tunguska airburst centennial in 2008 was a reminder that asteroid and comet impacts are rare but inevitable. At the present time, the only feasible impact prevention methods are deflection or disruption and dispersal of the object using nuclear munitions or a kinetic impactor [1]. Assuming technical readiness, implementation depends on such variables as time to impact, composition, size, and trajectory of the individual PHO; variables which are now known to a useful degree of certainty.

Methods

Energy from a nuclear burst is delivered to a target by neutrons, gamma rays, x-rays, and plasma. The neutrons and gamma rays reach the target before the x-rays and plasma [2]. We use the particle transport code MCNP to model the deposition of energy from the neutrons and gamma rays. The target does not have time to respond hydrodynamically to the initial deposition of neutron and gamma energy, so it can be modeled as a static object in MCNP. The energy deposition from x-rays, hydrodynamic response of the target, and interaction with the expanding plasma fireball from the device are modeled with the RAGE code.

We use the Radiation Grid Eulerian (RAGE) hydrocode. RAGE is an Eulerian hydrocode with continuous adaptive mesh refinement (CAMR). It uses a gray diffusion model for radiative transfer using ux-limited nonequilibrium (two-temperature) diffusion, and tabular opacities. We use the SESAME equation of state and opacity tables [3]. For comprehensive descriptions of the code and verification and validation tests it has undergone, see [4] and [5]

MCNP is a general-purpose particle transport code used to model neutron, photon, and electron transport for medical physics, reactor design, and other applications including modelling the propagation of epithermal neutrons through the Martian regolith [6] . It is a massively parallel code that can conduct simulations in 1-3 dimensions and complicated geometries. It uses current nuclear cross section data where available, and fills in the gaps with analytical models where data are not available. MCNP has undergone extensive verification and validation [7].

Stand-Off Burst Model Initial Conditions

We model deflection scenarios for 25143 Itokawa because, although it is not a PHO, it was so well characterized by the Hayabusa mission [8], and a composition like other objects that are potential threats. We begin with two 2-D axisymmetric RAGE models of nuclear standoff bursts. Energy deposition and target response to a stand-off burst are not as well constrained as for a buried energy source. Ahrens and Harris (1994) [9] estimate a total yield of order 100 kt would be required to impart a Δv of 1 cm/s to a 1-km-diameter asteroid, given a geometrically optimal stand off distance, h/R = 0.414. We take their estimates as a starting point, and model a 100 kt burst 52 m away from the object shaped like asteroid Itokawa [10] on a line perpendicular to the plane of the shorter axes, which is presented here, and a second model of a 100 kt burst 104 m away from the object along a line perpendicular to its long axis, which will also be shown at the meeting.

Energy Deposition:

As explained above, energy is deposited into the target in two phases, explored by two separate models. Gamma ray and neutron interaction with the target are modeled in MCNP, while x-ray energy deposition, the thin plasma “fireball” and the object’s hydrodynamic response are modeled in RAGE.

Particle Transport: The source is a point source emitter with a 100 kt total energy and a particle energy spectrum taken from the Trinity experiment. The target is an Itokawa-shaped basalt object with a mesh that increases in resolution near it’s surface. A 100,000 particle model (Figure 1) of a 100 kt burst indicates significant energy deposition on the burst-facing side of the target, with a deposition depth less than 12 meters.

Radiation Hydrodynamics: The object is modeled with a minimum mesh resolution of 25 cm as porous SESAME Nevada Alluvium with an initial compressive strength of 0.2 bar, up to an assumed 1 kbar pressure to crush it completely, after which the material strength is

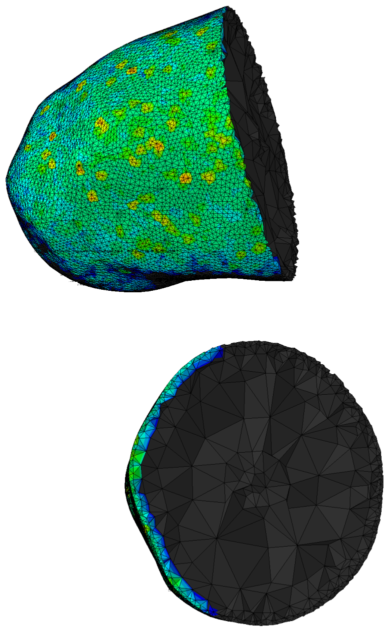

Figure 1: Energy deposition in an Itokawa-like basalt target from gamma rays and neutrons, calculated in MCNP.

set to zero. The source is approximated by a small aluminum sphere with 100 kt of internal energy.

Energy is deposited by x-rays in a thin outer layer of the target material. Some material is vaporized off the target. Other material is driven into the target and away from the location of the burst. As the plasma "fireball" expands away from the location of the burst and envelops the target object, it exerts a slight push into the target and away from the location of the burst, altering the direction of flight of material vaporizing off the target surface. Figure 2 shows the energy absorbed by the target from x-rays over time.

Further result at later times and from the model of the stand-off burst perpendicular to the plane of the long axis of the object.

Conclusions:

Here we present numerical models of the deposition of energy from a nuclear stand-off burst into a basaltic asteroid-shaped target. Future work will include importing MCNP energy deposition tallies into RAGE model initial conditions, and exploring the effects of target material properties, such as porosity, brittle failure, and granular material dynamics on shock propagation in

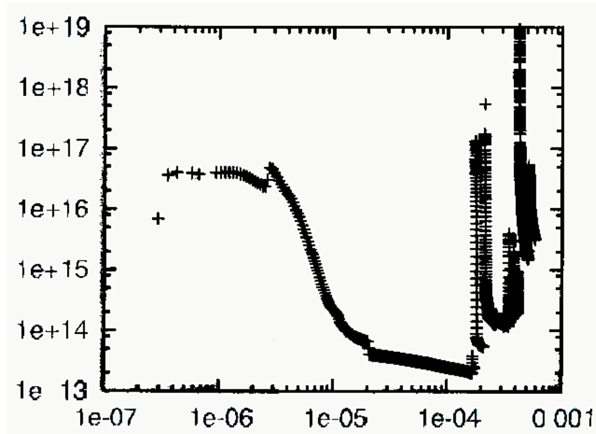

Figure 2: X-ray energy [ergs] absorbed by the target over time [s], modeled in RAGE.

models of asteroidal and cometary materials.

References

[1] NASA. Technical report, NASA Office of Program Analysis and Evaluation, (2007). [2] *The Effects of Nuclear Weapons*. U.S. Government Printing Office, (1977). [3] Johnson, J. D. In *Proc.12th Symposium on Thermophysical Properties*. Los Alamos National Laboratory, June (1994). LA-UR-94-1451.
[4] M. L. Gittings, e. a. *Computational Science and Discovery* **1**(1), 015005–+ October (2008). [5] Plesko, C. S. *Automated Feature Detection and Hydrocode Modeling of Impact-Related Structures on Mars*. PhD thesis, U. C. Santa Cruz, (2009). [6] Feldman, W. C., e. a. *Journal of Geophysical Research* **109**(E9) Sept. (2004). [7] et al., F. B. B. *Trans. Am. Nuc. Soc.* **87**(273) November (2002). [8] Fujiwara, A., Kawaguchi, J., Yeomans, D. K., Abe, M., Mukai, T., Okada, T., Saito, J., Yano, H., Yoshikawa, M., Scheeres, D. J., Barnouin-Jha, O., Cheng, A. F., Demura, H., Gaskell, R. W., Hirata, N., Ikeda, H., Kominato, T., Miyamoto, H., Nakamura, A. M., Nakamura, R., Sasaki, S., and Uesugi, K. *Science* **312**(5778), 1330–1334 (2006). [9] Ahrens, T. J. and Harris, A. W. In *Hazards Due to Comets and Asteroids,* Gehrels, T., Matthews, M. S., and Schumann, A. M., editors, (1994). [10] Ostro, S. J., Benner, L. A. M., Nolan, M. C., Magri, C., Giorgini, J. D., Scheeres, D. J., Broschart, S. B., Kaasalainen, M., Vokrouhlický, D., Chesley, S. R., Margot, J., Jurgens, R. F., Rose, R., Yeomans, D. K., Suzuku, S., and de Jong, E. M. *Meteoritics and Planetary Science* **39**, 407–424 March (2004).