EXPLORING THE DEFLECTION OF POTENTIALLY HAZARDOUS OBJECTS BY STAND-OFF BURSTS.

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Introduction: The recent discovery of Asteroid 2007 WD5's close approach to Mars [1] is a reminder that asteroid impacts are a rare but inevitable occurrence, and that potentially hazardous objects (PHOs) cannot always be discovered well in advance of a close approach. The prevention of impacts on Earth is a subject of varied research and debate. The only methods of impact prevention currently available are deflection or disruption and dispersal by nuclear or chemical explosion or a kinetic impactor. The best method to use depends on the individual scenario; mainly the time to impact, and the composition and trajectory of the PHO. The possible and likely ranges of PHO properties are a subject of ongoing research, and are now known with a useful degree of certainty [2-7].

Advances in compute power and hydrocode model sophistication now allows complicated problems that involve detailed interactions between matter and radiation in multiple dimensions to be explored in detail [8]. Here we build on previous PHO scenario modeling efforts with the intent of preparing contributions for a 'PHO Playbook', a collection of scenarios and applicable strategies, ideally prepared well in advance of any such incident. We begin by exploring the parameter space of PHO composition and dynamics, and using hydrocode models informed by previous efforts [9-11] to constrain what it would take to avert a collision.

We begin by modeling deflection by momentum transfer from a stand-off nuclear burst. Nuclear stand-off burst is the simplest, highest energy-density choice of those options that are currently technologically mature enough for immediate deployment. It has the further advantage of being comparatively easy to model in a radiation-enabled hydrocode.

Hydrocode Modeling Methods: There are several primary considerations for modeling asteroid deflection. The initial trajectory dictates the urgency of response and the magnitude of deflection required. Longer timescales require smaller changes, and allow multiple course corrections. Physical properties such as the shape, volume, and mass of the object may be determined along with trajectory information by RADAR studies [3]. The observed spectral type indicates chemical composition and places constraints on physical properties such as density. Missions such as Hayabusa, NEAR, Stardust, and Deep Impact returned significant information about the internal structure of asteroids and comets. This all allows us to explore likely internal configurations, and constrains Q_S^*, the energy required to shatter the body, an upper safety limit for stand-off bursts [10].

The RAGE Hydrocode. The Radiation Adaptive Grid Eulerian (RAGE) code is a version of the SAIC Adaptive Grid Eulerian (SAGE) hydrocode with radiative transfer enabled [12]. Simulations may be carried out in multiple dimensions, a variety of geometries, and with an arbitrary number of constitutive materials via the LANL SESAME database [13]. Elastic-Plastic and Tepla strength models, and a P-alpha crush model allow modeling of porous solids. OSO computational geometry design software allows development of detailed, realistic initial conditions. RAGE is usually used for gas- and fluid-dynamics problems where it is well validated [14-16]. We find that it also yields accurate and interesting results for shocks in solid materials [17]. The combination of sophisticated hydrodynamics, radiation transport, and the capacity to handle complicated structure in a variety of materials make RAGE a promising code for use in modeling asteroid deflection.

Project Goals: It is neither necessary nor possible to prevent PHOs of every size, type, and trajectory from hitting Earth. There is a cost of damage below which it is more cost-effective to mitigate and repair the damage locally. There is also an impactor size threshold above which current technology is ineffective, and new solutions must be developed [9, ch. 7]. Solem [18] did some initial analytical calculations and suggested mitigation strategies for asteroids as large as three kilometers diameter. His work was done without the benefit of physical property information from any of the small-body missions flown subsequently. Current efforts take advantage of that and research on small body properties like [10] and [19].

Momentum Coupling Parameter Study. We begin with asteroid deflection because it is both within the capabilities of the RAGE code to model, and within current world capabilities to carry out.

The first question is how do PHO geometry, composition, and physical properties (eg. surface roughness, strength, volatile content, etc.) affect the coupling of energy from the burst to the target? This is currently only known to within a couple orders of magnitude [11, 18]. We address this through a parameter study in which one property is changed for each case in order to demonstrate its effects.

The base case (figure 1) is a smooth 100-m diameter solid basalt sphere, and a 1 kT burst at a calculated optimum height of burst, $H = (2^{1/2}-1)R = 20$ m, after [11]. From there, the parameters are varied as shown in table 1 to test how they change the efficiency of momentum transfer.

Specific Scenarios. When these factors are better understood, they will inform specific models to be done for known objects or statistically significant scenarios, such as Apophis- or Tunguska-like impactors.

The eventual goal of this project is to assemble a range of specific mitigation actions, and characterize the range of scenarios over which such actions would be effective, such that if and when such a scenario arises, mitigation strategies are already at hand.

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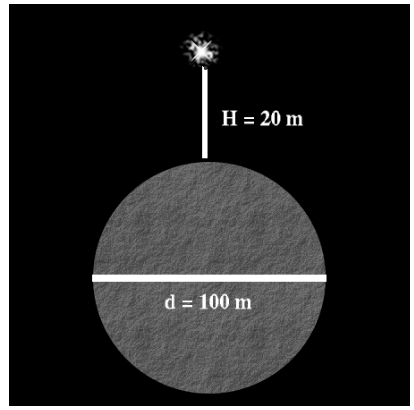

Figure 1: The simplest case initial conditions for a stand-off burst model consists of a 1 kiloton burst at 20 meters above a 100 meter diameter solid basalt sphere.

	Min	Expected	Max
Ellipticity	0	0.5	1
Topography and roughness	smooth	multi-scale, via observation	Comet Wild 2-like.
Volatiles	0%	5-50%	100%
Porosity	0%	20-50%	60%
Albedo	0%	5-12%	99%
Skin Depth	0	5-10 cm	10 cm

Table 1: Parameters of interest in determining burst-to-PHO energy coupling. Ellipticity, topography, and surface roughness determine available surface area. Volatile inventory affects how much material is blown off the blast-facing surface. Porosity strongly affects the attenuation of the shock and spall dynamics. Albedo and skin depth (how far neutrons can penetrate) also affect energy coupling.