IMPACT HAZARD MITIGATION RESEARCH AT LOS ALAMOS NATIONAL LABORATORY: CURRENT STATUS. C. S. Plesko[1], J. M. Ferguson[2], G. R. Gisler[2], R. P. Weaver[2], [1]Los Alamos National Laboratory, XTD-NTA (plesko@lanl.gov), [2]Los Alamos National Laboratory, XTD-IDA

Introduction: Los Alamos National Laboratory (LANL) has been tasked by the National Nuclear Security Agency (NNSA) to study the mitigation of the impact hazard of asteroids and comets on the Earth as part of an inter-agency agreement (IAA) with NASA. We are modeling deflection or disruption of a hazardous object by kinetic impactor, nuclear burst, or a combined nuclear impactor. Kinetic impactors transfer momentum directly through impact and through a target-dependent momentum enhancement by ejected target material. Nuclear devices impart momentum to the target object by vaporizing target material and lofting it, and in some cases entrained solid material, away from the body.

NASA/NNSA IAA: NASA and NNSA have entered into an inter-agency agreement to study the prevention of asteroid or comet impacts on Earth by modifying the orbit or disrupting and dispersing the potentially hazardous object (PHO) using either a kinetic impactor, a notional nuclear explosive device (NED), or a combined impactor and NED, delivered by a spacecraft. As part of the IAA, LANL has been tasked with modeling the deposition of energy into a PHO and its response. We are using the OSIRIS-REx team's prelaunch understanding of asteroid Bennu as an estimate of the most information we would have before a mitigation attempt. In the majority of cases, we expect to know less. OSIRIS-REx data return will provide post-hoc ground truth to check our assumptions against.

Design Reference Asteroid 1 (DRA1), Bennu: We cannot assume that spacecraft reconnaissance data will be available for a specific PHO prior to a mitigation attempt. The deflection mission would likely be the first spacecraft rendezvous. Spacecraft reconnaissance data is most valuable to us as aggregate information about the diversity of objects we might encounter, particularly information about possible internal structure and composition, macro- and micro-porosity, and the heterogeneity of structure and composition observed for a given object and across dynamical families and spectral types. Our models draw on the OSIRIS-REx DRA [1], and add specific simplifications and assumptions where necessary for the completion of our models [2]. We simplify the model to be a 500-m-diameter sphere of 1 g/cc density dry SiO_2, homogeneous sub-mesh porosity, Steinberg-Guinan strength, deflected by either a kinetic impactor or a 1 MT stand-off nuclear burst at 100 m above the surface. There are two extension models, DRA 2, Didymoon, the 100-m-diameter moon of Didymos, and DRA3, which will be comet-like.

Methods: We use several numerical methods to model energy deposition and predict target response.

Hydrocode Models of Impacts. We use the RAGE hydrocode [3] with several strength and porosity models to simulate the impact of different impactors into target asteroids of varying shape and composition, including both sub-mesh scale and macro-scale voids.

Hydrocode Models of X-ray Energy Deposition. Approximately 97% of the energy emitted by a nuclear device is in the form of kinetic energy (debris) and thermal radiation (x-rays). We model this portion of the energy using the RAGE hydocode's gray diffusion radiation transport model that simulates the flow of wavelike light in a problem in combination with the SESAME equation of state and opacity tables [4]. Gray diffusion is similar to a black body model except the bodies absorb and radiate with an inefficiency, $\sigma < 1$.

Particle Transport Code Models of Neutron Energy Deposition. The remaining energy is released as nuclear radiation (neutrons and gamma rays), which deposit their energy much deeper in the target than x-rays do, so they may have a significant effect on the amount of debris and momentum ejected from the surface. We model the nuclear radiation energy deposition using the MCNP particle transport code [5].

Model Results to Date: We have conducted a series of verification and validation models previously [6][7]. Currently, we are modeling a simplified analog of asteroid Bennu, the Osiris-REX mission target, in collaboration with Lawrence Livermore National Laboratory [8], who are modeling the same target.

Impact models conducted by Gisler use a 64-cm-diameter impactor striking the target at 20 km/s. He is exploring the effects of target properties on momentum enhancement. X-ray deposition models by Weaver, Plesko, and Ferguson, explore the dynamic response of both solid objects and those with macro-scale porosity, and the energy required to disrupt km-scale bodies. MCNP models by Ferguson explore the dependence of neutron energy deposition on object composition.

Nuclear Stand-Off Burst Models: We are modeling the deposition of energy from a nuclear stand-off burst into DRA1 using a two-pronged approach. We model energy deposition by neutrons using MCNP (Fig.1). We are using the RAGE hydrocode to model the deposition of energy from x-rays into the DRA1 target surface (Fig. 2).

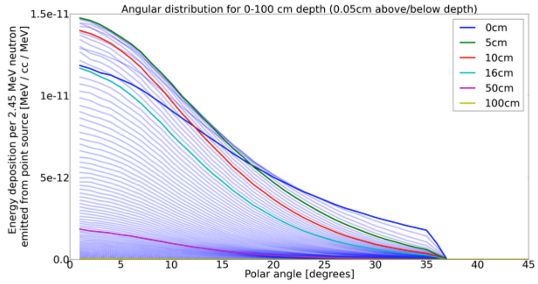

Fig. 1: MCNP predictions of energy deposition by 2.45 MeV neutrons vs. polar angle to a depth of 100 cm on DRA 1 by Ferguson.

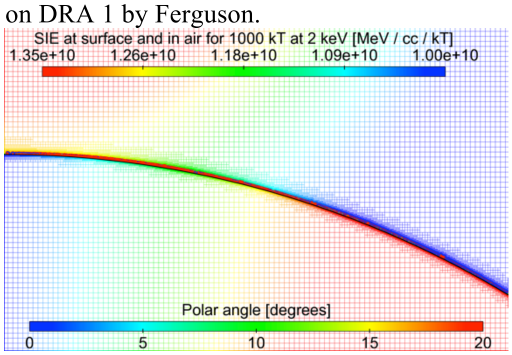

Fig. 2: RAGE predictions of energy deposition by 2 keV x-rays on DRA 1 by Ferguson.

Nuclear Impactor Models: Weaver is modeling the Hypervelocity Asteroid Intercept Vehicle (HAIV) nuclear impactor scenario [9], the impact, nuclear burst, and target response using RAGE. The current mission plan is no more efficient than a contact burst alone (Fig. 3). If the impactor is redesigned to increase the depth to diameter ratio of the crater in the contact and compression and early inertial regimes, a factor of 4-20 improvement in energy deposition can be gained.

Kinetic Impactor Models: Gisler is modeling kinetic impactors into DRA 2. The transfer of momentum between projectile and asteroid occurs within the first millisecond. The ejecta boil off later, increasing the negative axial velocity of the remaining material.

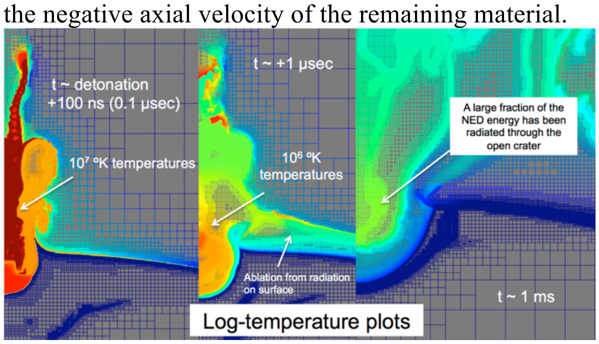

Fig. 3: RAGE radiation hydrodynamics model of the HAIV nuclear impactor mission concept.

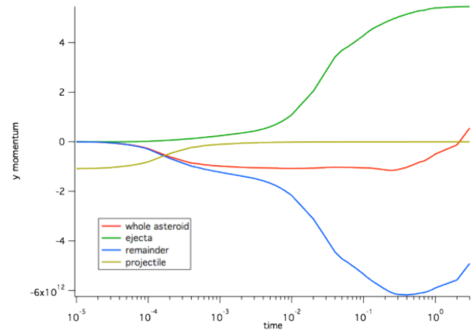

Fig. 4: RAGE predictions of momentum deposition by kinetic impactor to DRA 2.

Equation of State (EOS) Validation: Our DRA 1 models begin with the simplest EOS that are useful for the problem, in order to facilitate comparison between the models being done in various codes. As we move to more sophisticated scenario models, we will need to use EOSs with grater fidelity. Construction of meteoritic EOSs is ongoing but incomplete. Until they are ready, Plesko is building comparisons of available meteorite EOS data to existing SESAME EOSs. Meteorite shock data is quite variable within each sample, which is unsurprising for heterogeneous objects. Iron content increases density and makes their principal Hugoniots behave more like perovskite. Hydration and increased carbon content make samples less dense, and their principal Hugoniots behave like clays. A variety of EOSs and models for any given scenario are needed in order to constrain the range of possible delta v imparted to a target for which samples are unavailable.

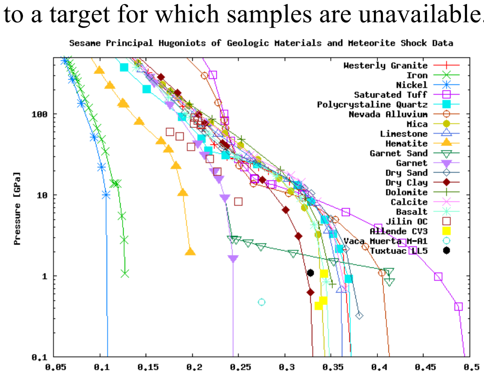

Fig. 3: A comparison of principal Hugoniots of SESAME EOSs with meteorite shock data shows in-sample and across type variability.

References: [1] Hergenrother C. W., et al. *Icarus 226:663–670, 2014.* [2] Plesko, C. S., et al, AGU 2015. [3] Gittings M. L. et al., Comp. Sci. Disc 1, 2008. [4] Lyon, S. P., Johnson, LA-UR-92-3407, 1992. [5] Brown, F. B., Trans. Am. Nuc. Soc. 87, 2002. [6] Plesko, C. S. Thesis, UCSC, 2009. [7] Weaver, R. P., et al. Acta Astron. 2014. [8] Howley, K. et al., Acta Astron., 2014. [9] Wie, B. Acta Astron., 2013.