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Title: Impact Hazard Mitigation: Understanding the Effects of Nuclear Explosive Outputs on Comets and Asteroids

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Impact Hazard Mitigation: Understanding the Effects of Nuclear Explosive Outputs on Comets and Asteroids

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ABSTRACT

The NASA 2007 white paper "Near-Earth Object Survey and Deflection Analysis of Alternatives" affirms deflection as the safest and most effective means of potentially hazardous object (PHO) impact prevention. It also calls for further studies of object deflection. In principle, deflection of a PHO may be accomplished by using kinetic impactors, chemical explosives, gravity tractors, solar sails, or nuclear munitions. Of the sudden impulse options, nuclear munitions are by far the most efficient in terms of yield-per-unit-mass launched and are technically mature. However, there are still significant questions about the response of a comet or asteroid to a nuclear burst. Recent and ongoing observational and experimental work is revolutionizing our understanding of the physical and chemical properties of these bodies (e.g., Ryan (2000), Fujiwara et al. (2006), and Jedicke et al. (2006)). The combination of this improved understanding of small solar-system bodies combined with current state-of-the-art modeling and simulation capabilities, which have also improved dramatically in recent years, allow for a science-based, comprehensive study of PHO mitigation techniques. Here we present an examination of the effects of radiation from a nuclear explosion on potentially hazardous asteroids and comets through Monte Carlo N-Particle code (MCNP) simulation techniques.

MCNP is a general-purpose particle transport code commonly used to model neutron, photon, and electron transport for medical physics, reactor design and safety, accelerator target and detector design, and a variety of other applications including modeling the propagation of epithermal neutrons through the Martian regolith (Prettyman 2002). It is a massively parallel code that can conduct simulations in 1–3 dimensions, complicated geometries, and with extremely powerful variance reduction techniques. 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 and is considered the gold-standard for particle transport. (Forrest B. Brown, et al., "MCNP Version 5," *Trans. Am. Nucl. Soc.*, **87**, 273, November 2002.) Additionally, a new simulation capability using MCNP has become available to this collaboration. The first results of this new capability will also be presented.

In particular, we will show results of neutron and gamma-ray energy deposition and flux as a function of material depth, composition, density, geometry, and distance from the source (nuclear burst). We will also discuss the benefits and shortcomings of linear Monte Carlo. Finally, we will set the stage for the correct usage and limitations of these results in coupled radiation-hydrodynamic calculations (see Plesko *et al*, this conference).

1. MOTIVATION AND PURPOSE

A detailed understanding of the nature of the threat faced by the Earth or any of the planets in our solar system, for that matter, is not known. However, it is known with absolute certainty that the Earth and the other planets of our solar system have been and continue to be hit by asteroids and/or comets with a wide variety of shapes, sizes, compositions and velocities. In fact, this very summer, Jupiter was hit once again with an impact estimated to be in the tens of gigatons[1]! A strike on the earth of that magnitude, depending on several key factors, would kill millions of humans and could kill billions; the consequences would be global and have a lasting effect.

The human race and subsequently the rest of the life on our planet find our selves in an interesting crossroads in our history. That is, while we may have the ability to purposefully end most of the life on our planet with nuclear weapons we also have the potential to save it by the same technology. The unique combination of the last viable peaceful use of nuclear weapons with the first potentially preventable natural disaster is too important to leave unstudied and in a state of uncertainty given the political challenges faced by such a marriage.

While popular in movies, print and other publicly oriented media simply "blowing-up" and asteroid or comet is generally not considered the best option due to the possibility of turning one large problem into many smaller yet potentially devastating problems. Further, the scientific investigation of using nuclear explosives to prevent impacts from large comets and asteroids has a relatively well established technical basis as can be seen, for example, in [2-4]. In the text that follows we will detail our efforts to begin to understand using the various radiations produced in a nuclear explosion to impulsively impart momentum through ablation of the potentially hazardous object's (PHO) surface with several current state-of-the-art computational resources with the hope of providing new insights into this challenge.

2. SIMULATION CHALLENGE

In order to computationally study the effects of radiation produced by a nuclear explosive we need a simulation capability that can handle:
- Hydrodynamics
- X-ray and gamma-ray transport
- Neutron transport
- High-fidelity multi-dimensional geometries
- High-performance parallel computing

Unfortunately, there is no scientific software available that does all of this in a fully coupled or even self-consistent manner. However, we may make clever use of combinations of several simulation tools.

A careful analysis of the relevant physics indicates that the study of ablation requires a coupled radiation-hydrodynamics code due to the interaction of the material temperature and radiation opacity in a hydrodynamically active (expansion) region. Further, we find that neutron and gamma-ray transport may be accomplished separately from the hydrodynamics calculation due to the large mean-free-paths (mfp) of these, largely, non-equilibrium particles. Therefore, we may take energy depositions calculated from the neutron and gamma-ray components and source them back into the hydrodynamic calculations.

We have chosen to use the Los Alamos National Laboratory (LANL) and Science International Applications Corporation (SAIC) Radiative Adaptive Grid Eulerian (RAGE)[6] code to handle the radiation-hydronamics calculation[5] and the LANL Monte-Carlo N-Particle (MCNP) code to handle the neutron transport.

Fig. 1 depicts the ablation, in orange, from an idealized ice-like comet after being heated by a shock from a hypothetical nuclear source and demonstrates some of the capabilities of the RAGE code.
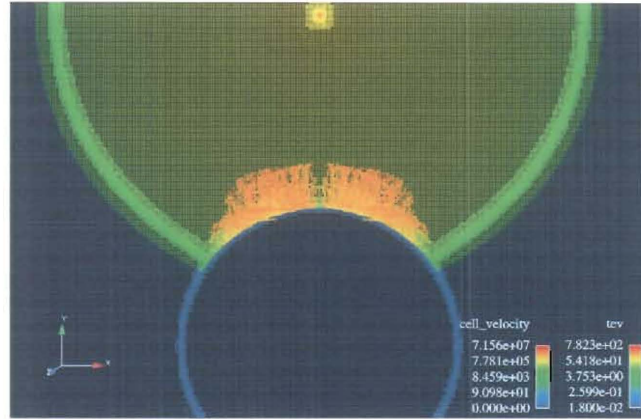
Fig. 1. RAGE plot of the temperature of the expanding shock from the burst location, and the velocity (colored vectors) of the ablated material coming off of the ice sphere 300 ns after detonation.

While RAGE is an outstanding candidate to handle much of the radiation-hydrodynamics needs of this problem MCNP "as is" is not. That is, MCNP is the "gold-standard" in neutron transport but it lacks an easy way to handle complicated geometries, subsequent meshing and 3-D visualization. Fortunately, a link between MCNP and Abaqus/CAE was developed at LANL that eliminates these shortcomings.

As a proof-of-principle we performed a neutron energy deposition calculation using the newly developed MCNP-Abaqus/CAE link. To demonstrate the power of this combination we chose the asteroid Itokawa[9], due to the quality of the data shown in Fig. 2, and the well-studied neutron output spectrum[10] of a 21 kt nuclear weapon, shown in Fig. 3. The actual MCNP mesh, generated in Abaqus/CAE, is based on a NASA shapefile with 20-m resolution and is shown in Fig. 4.
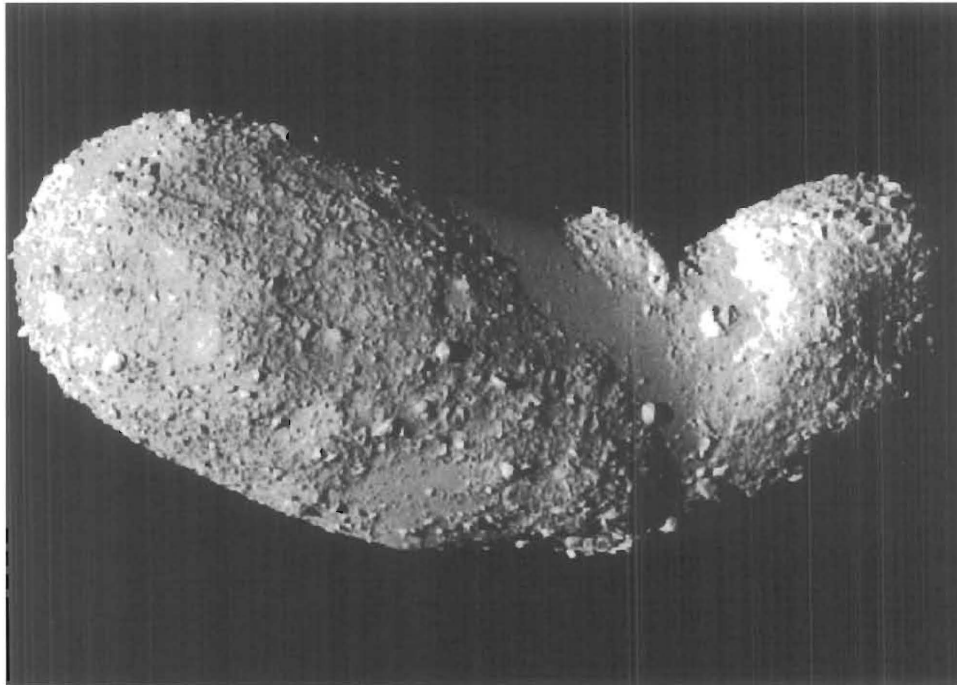

Fig. 2. Asteroid Itokawa by JAXA with a resolution better than 1 meter.
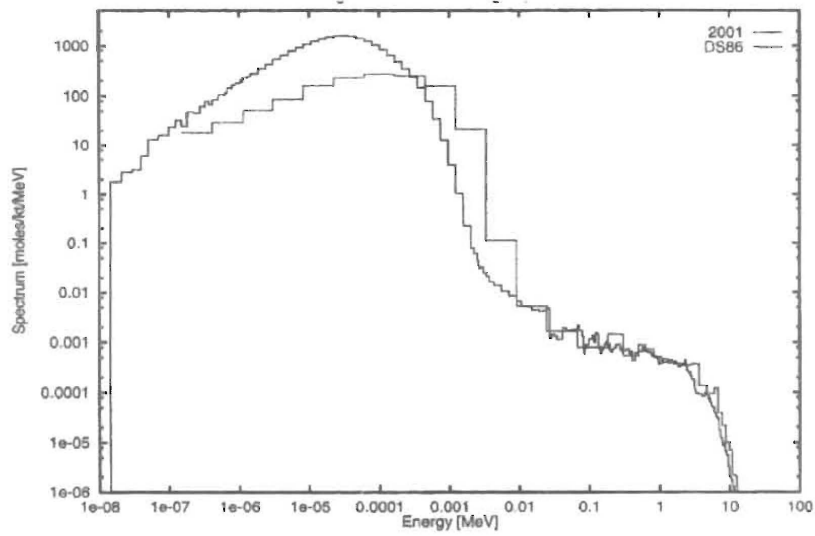
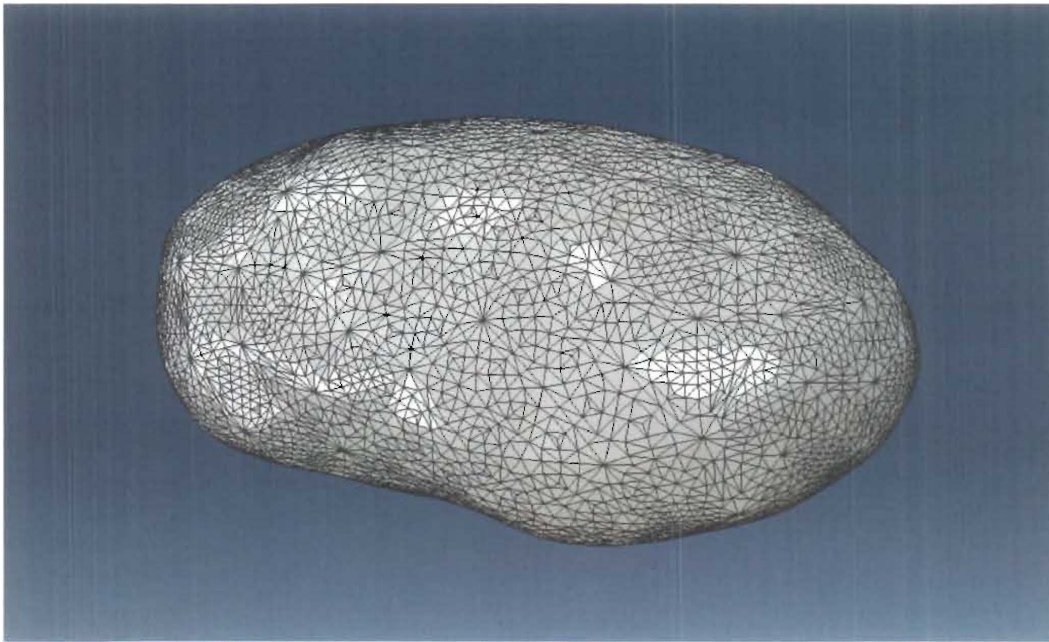Fig. 3. Neutron spectrum from a 21kt nuclear weapon.

Fig. 4. Abaqus/CAE representation based on NASA shapefile data from Goldstone Radio Telescope with 20-m resolution.

A simulation consisting of 100,000 histories was ran in MCNP and produced energy deposition results shown in Fig.'s 5-7.
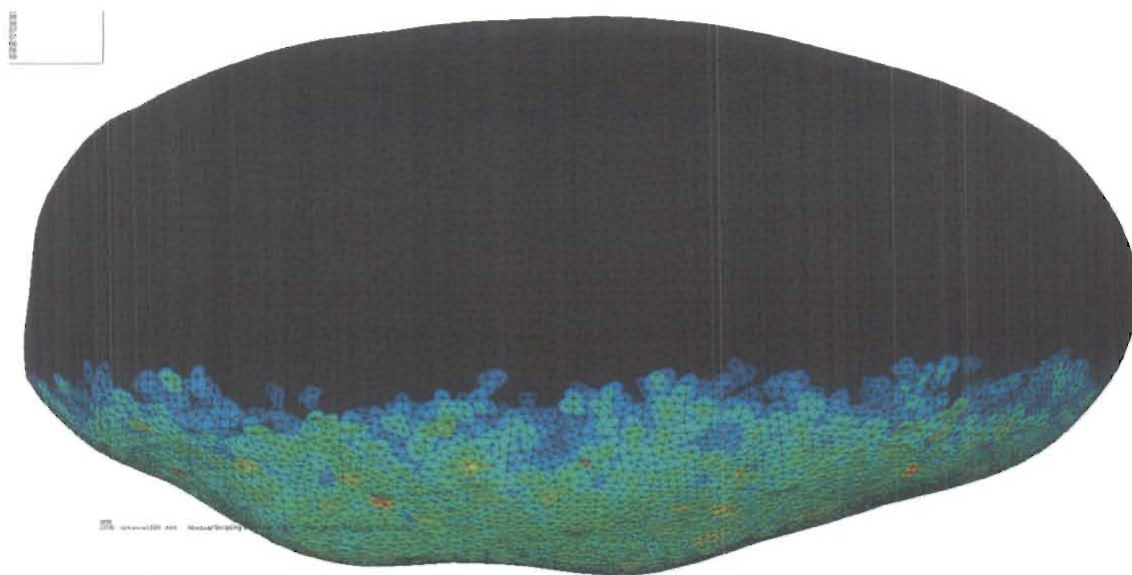
Fig. 5. Color-coded surface plot of energy deposition on a model of asteroid Itokawa. The neutron source would be below the figure, for spatial reference.
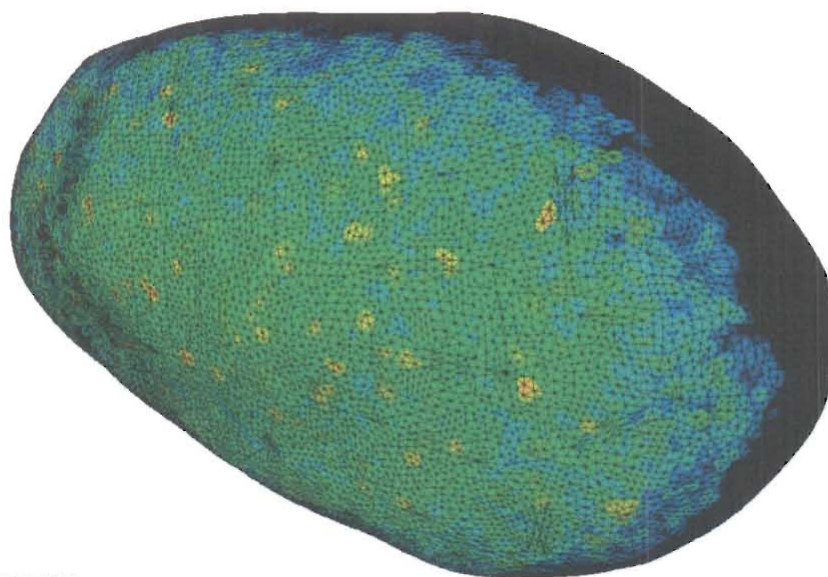

Fig. 6. Another view of the surface energy deposition shown in Fig. 5. The neutron source would be to the left of the figure, for spatial reference.
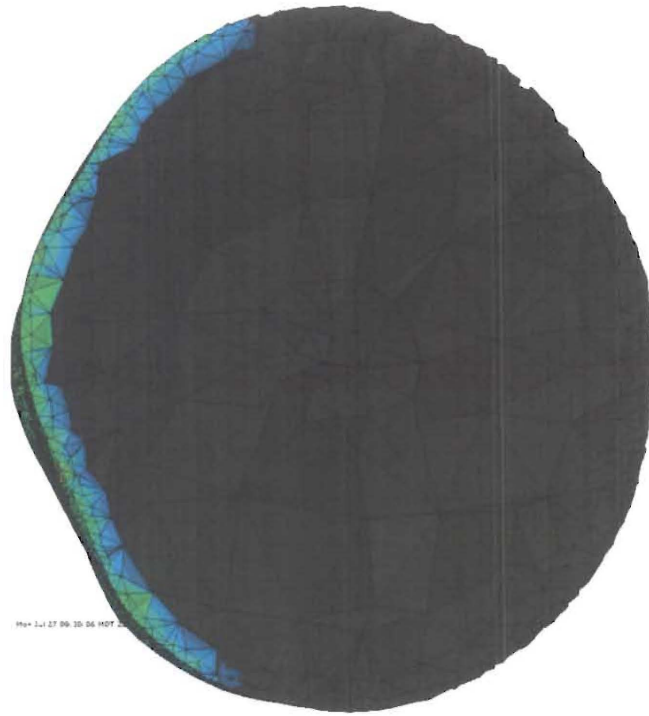
Fig. 7. A cutaway of the asteroid Itokawa simulation showing volume energy deposition. The depth of penetration of neutron energy is approximately 15-m. The neutron source would be to the left of the figure, for spatial reference.

3. FUTURE WORK

The first efforts to demonstrate the usefulness of LANL's new MCNP-Abaqus/CAE capability have been promising. We now posses the capability to study any PHO geometry and material combination with realistic neutron sources. However, much work is yet to be completed, e.g.: Optimization of the mesh, increasing the number of histories sampled, using mono-energetic sources to deconvolve energy effects, and simulating a complete suite of materials for PHOs.

We are beginning to source energy deposition from these MCNP-Abaqus/CAE calculations into our RAGE simulations to study the effects neutron driven ablation, which is also very promising. The completion of a full suite of simulations remains to be done.

4. REFERENCES

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