THE RESPONSE OF METEORITIC AND COMETARY MATERIALS TO NEUTRON BOMBARDMENT.

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Introduction: The asteroid and comet impact hazard is in the forefront of public and scientific consciousness after the recent Chelyabinsk impact, the near miss of asteroid DA14, and the disintegration of comet ISON. A possible hazard mitigation method under consideration is deflection or disruption by nuclear burst. Before we can say with certainty that an explosive yield Y at height or depth of burst h will produce a momentum change in or dispersion of a potentially hazardous object (PHO), we need to quantify how and where energy is deposited into the rubble pile or conglomerate that may make up the PHO. One part of that energy comes from neutrons. Here I present particle transport models of energy deposition from a neutron source into various materials that are known PHO constituents. These models can be used to predict the Mean Free Path (MFP) of neutrons in the materials, where they deposit their energy, and any isotopic changes (in this case very small) that may be caused by neutron bombardment of these materials.

Background: Nuclear mitigation of potentially hazardous asteroids and cometary nuclei (PHO's) depends on the absorption of x-rays and neutrons by the target object, and how the object then responds to energy deposition. The absorption of x-rays has been studied experimentally by Remo et al. [1]. Neutron absorption by geologic materials in general has been reported in [2] . The nuclear mitigation problem in porous rubble piles depends on volatilization of some part of the target. Neutron energy must be relatively high (>1 eV) in order to contribute to volatilization. Lower energy neutrons can interact with the crystal structure of a material (e.g. Bragg scattering), while the higher-energy neutrons in this problem interact with the atomic structure of the constituent elements. This simplifies the problem by allowing us to model nuclear cross-sections as weighted sums of the cross-sections of different elements and neglect further mineralogical details. The cross-section of an atom depends on its nuclear structure, and can contain resonances, or narrow energy bands at which the probability of interaction is higher. These cross-sections, including averaged values for chondritic populations of isotopes of various elements are determined by experiment, reviewed, and tabulated by several governing bodies.

Methods: I use meteoritic compositions from [3], [4] and [5], [6] for the refractory component of cometary nuclei as representative small body compositions for these models. I then used these compositions and experimental nuclear cross-section data from [7] to make neutron scattering and absorbtion cross-sections for various meteorite types, devolatilized cometary refractories, and various mixtures of cometary volatile and refractory elements. With these cross-sections, and the published estimates of the neutron energy spectrum from [8], I then use the MCNP particle transport code [9] to calculate neutron scattering, energy deposition, and the possibility of isotope production in nuclear mitigation of a PHO.

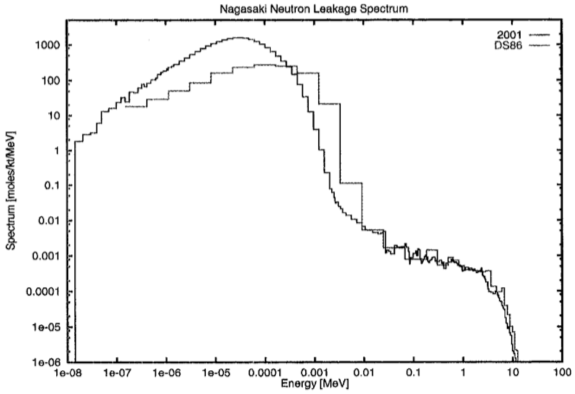

Fig. 1: Estimated neutron energy spectrum of the nuclear explosion at Nagasaki, Japan. The higher-resolution 2001 curve was used in this work. The ordinate is the spectrum in moles of neutrons per kt, per MeV, the abscissa is energy in MeV.

Results: Results for CI chondrite meteorites of a composition reported by [3] are presented here. Results for other compositions will be presented at the meeting.

CI Chondrite Cross-Section. A neutron cross-section is the probability of a neutron interacting with a given material, as a function of neutron energy. As described above, it is a mass-weighted sum of the cross-sections of the atoms that make up the material. The CI chondrite used here contains more than 60 different elements. The diverse composition of the object results in a relatively resonance-free cross-section because the resonances in the cross-sections of the constituent elemets average out over a heterogeneous composition. Objects that have more homogeneous compositions will have stronger resonance peaks.

Energy deposition as a function of depth. Particle transport codes like MCNP use a source energy spectrum (Fig. 1) and target nuclear cross-section (Fig. 2) to model the interactions of the large numbers of neutrons released from a nuclear device with the large number of atoms in the target material. For this energy spectrum and cross-section, the mean free path (MFP) of neutrons in the target is 2-3 cm of solid material. If the regolith were porous, the MFP would increase as ρ_0/ρ, so for a regolith density of 1.5 g/cm^3, the in-situ MFP would be 3-4 cm, and the energy deposition falls off approximately exponentially in the MFP [10].

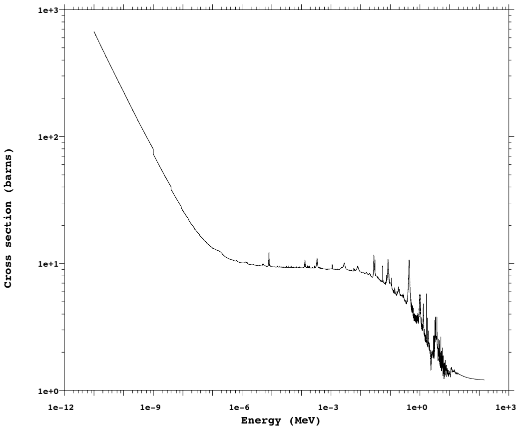

Fig. 2**:** Nuclear cross-section of a CI chondrite, calculated using MCNP and [3]. The ordinate is is the cross-section in barns, the abscissa is energy in MeV.

Isotope Production. Neutrons can interact with an atom in a variety of ways. Sometimes the end product of these interactions are one or more daughter isotopes different from the original atom. There has been concern in the popular press that unstable iosotopes generated by a nuclear deflection attempt may prove hazardous itself. While the relatively large distances and relatively small masses involved make this unlikely, detailed estimates of isotope production may be derived from transport calculations like those reported here.

The main components by mass of a CI chondrite are Fe, Si, Ni, H, C, and S. Of these, only ^{58}Ni, about 70% of natural Ni, can produce an unstable isotope, through the reaction ^{58}Ni(n,d)^{57}Co, but the reaction has a relatively low probability, and is not predicted to occur by this simulation. At lower abundances, phosporus, which is present at concentrations of 920 ppm, undergoes an n-γ reaction and produces ^{32}P, $4.16 \times 10^{-6} \pm 0.003\%$ g/kt absorbed by the target, which has a half-life of 14.28 days.

Conclusions: I am using the MCNP particle transport code, nuclear data from the ENDF nuclear data libraries, and compositions from published studies of meteorites and sample returns from Hayabusa and Stardust to explore the response of meteoritic and refractory cometary materials to neutron bombardment at energies relevant to the impact hazard mitigation problem. Mean free paths of neutrons in the target materials are of order 1-10's of cm for solid targets, and increase as the target density decreases. Daughter isotope production from neutron bombardment can be estimated, but for CI chondrites and other targets whose constituents produce predominantly stable daughter products under these conditions, the production of unstable products is predicted to be vanishingly small.

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