Comments on the primary impactor flux sections of the NESC-RP-20-01576 Lunar Ejecta Report

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The sections pertaining to the primary impactor flux in NESC-RP-20-01576 have been reviewed. Three important oversights in these sections have been found and are outlined below.

1 The boundary between the meteoroid and asteroid populations

MeMoSeE utilizes the Meteoroid Engineering Model (MEM) version 3 to describe the primary meteoroid flux upon the lunar surface. This is a good choice, as the model matches ground-based and in situ observations, has been peer reviewed in numerous publications and NRC/NESC studies, and is in the design specifications for lunar spacecraft and landers. However, MeMoSeE uses MEM's upper mass limit of 10 grams as the boundary between the meteoroid/asteroidal flux, which is blatantly wrong in light of our current understanding. The 10 gram upper limit for MEM was an arbitrary choice, based on the realization that the meteoroid flux at this and larger masses was too small to be of any consequence in spacecraft design or hazard assessments. There was no physical reason for this limit, and the reason the MeMoSeE developers chose this as the boundary between meteoroid and asteroid impactors is a mystery, other than it was convenient.

So what is an appropriate boundary between the meteoroid population, represented by MEM, and the asteroid population? Well over 90% of meteoroids come from comets, ejected when the ices on the nucleus sublimate into gases. These gases "drag" the meteoroids along with them as they escape into space. This mechanism is fairly efficient for particles up to a decimeter in size or $\sim$1 kilogram in mass (Whipple, 1951; Beech and Nikolova, 1999). The numbers of these sub-kilogram cometary particles dwarf the contribution by asteroids, which is produced through fragmentations, collisions and sputtering. However, cometary meteoroids are few in number at masses greater than a kilogram, enabling meteoroids produced by the asteroids to catch up and dominate the natural particle environment. Thus we expect to see a small particle environment well characterized by MEM and meteor showers (cometary meteoroids),

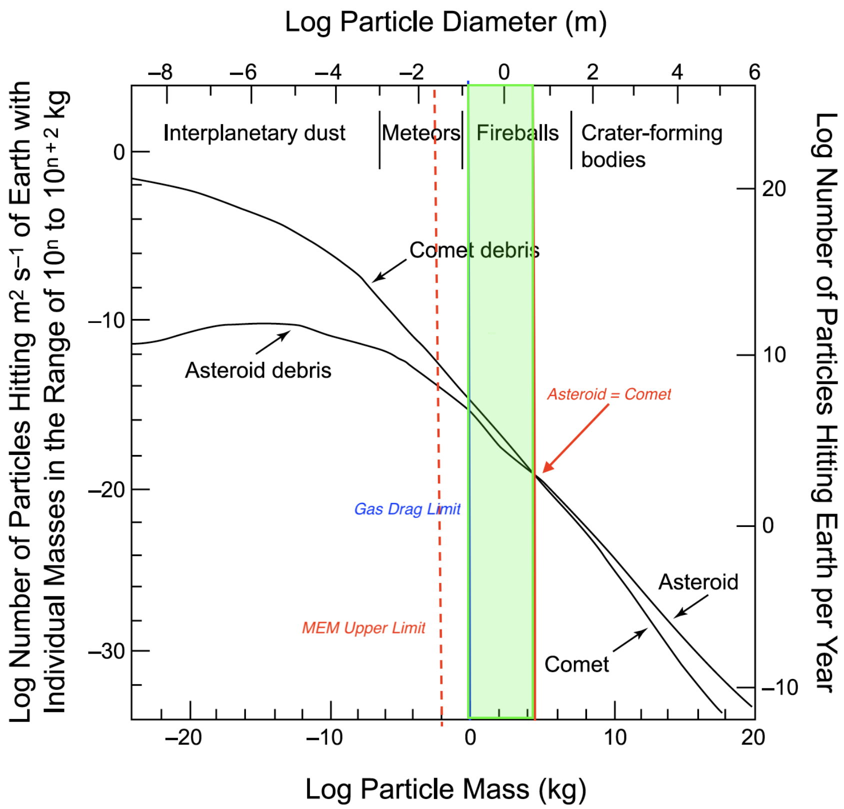

Figure 1: Cometary and asteroidal contribution to near-Earth flux. Adapted from Zolensky et al. (2006). Green band indicates the comet/asteroid particle transition region.

gradually transitioning to fragments from the NEO population starting around a kilogram. The NEO population should accurately depict the environment at masses larger than a hundred kilograms or so (Hughes, 1994).

Critique 1: ***The 10 gram boundary between the cometary and asteroid populations used in MeMoSeE is not supported by any observations or research, all of which indicate that the transition occurs at masses between 2 and 4 orders of magnitudes larger (1-100 kilograms).***

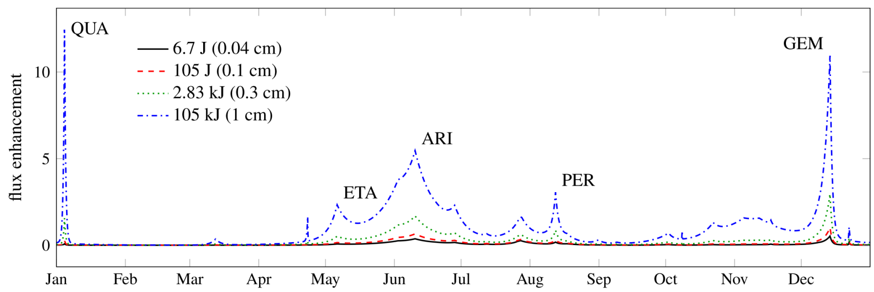

Figure 2: Representative meteor shower flux enhancements from Moorhead et al. (2019).

2 The contribution of meteor showers (Section 10.3)

The panel correctly points out that meteor showers dominate the flux for objects between 1 gram and 1 kilogram in mass. However, they dismiss this contribution by considering only the effects of the Geminid shower upon ejecta production. Even though the Geminids are usually the most intense annual meteor shower, there are several other showers occurring throughout the year that also can produce ejecta. At least one of these, the Arietids, has an integrated flux several times that of the Geminids and is part of an ensemble of late spring/early summer showers that contribute significantly to the large particle flux (Figure 2). Furthermore, the daytime β Taurids are known to have produced outbursts of meteoroids possessing sufficient impact energy to be detected by the Apollo seismometers left on the Moon in the 1970's (Duennebier et al., 1976).

Critique 2: ***The consideration of a single meteor shower, no matter how intense, is not sufficient to dismiss the contributions of meteor showers to ejecta production.***

3 The NEO population

In section 7.2, the panel reviews MeMoSeE's model for the NEO population, identifying issues with scaling the flux (Brown et al., 2002) and the likelihood of biases in the CNEOS data used to construct the speed distribution. To check the directionality, a "crude" model of the NEO population was constructed from NEOs contained within JPL's Small-Body Database. The results from this model did not show the concentration to the ecliptic that the MeMoSeE developers assumed. The panel, in its prior discussion of the speed distribution, states the proper corrective action - a full dynamical model needs to be used in obtaining the proper speed and directional distributions. So this author is currently at a loss to explain Recommendation 5:

Recommendation 5: *Consider replacing the NEO angular distribution with that of the low-density MEM population*

The distribution of NEOs bears no resemblance to that of the low-density MEM population, which originate from Halley-type and long period comets. Indeed the panel points this out, stating that the orbits of NEOs are more circular. So after criticizing MeMoSeE's use of the directionality of the MEM high density, JFC-based population, the panel then recommends using the MEM low density directionality, even though a) the parent body orbits are not similar and b) using a MEM distribution for NEOs is orders of magnitude beyond the valid range of the model. What should have been recommended is that the developers use a full dynamical model such as that of Granvik et al. (2018) or Bottke et al. (2002) to construct self consistent speed and directional distributions, as the panel did with their simpler model. This obviously involves considerable work, but it is certainly more correct than using a comet-based meteoroid model to describe the NEO directionality. The Bottke et al. model is a possible starting point, as it has been used by several researchers in looking at lunar impacts, e.g., Gallant and Gladman (2006). The Granvik et al. model is a 2018 update; its more extensive information probably makes it the better choice.

Critique 3: ***The panel's Recommendation 5 should be changed to recommend the development of speed and directional distributions using a full dynamical model. As it stands, Recommendation 5 is not only wrong, but promotes the misapplication of a standard NASA model.***

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