

RISK TO CIVILIZATION: A PLANETARY SCIENCE PERSPECTIVE; Clark R. Chapman (Planetary Science Inst., Tucson AZ) and David Morrison (Inst. for Astronomy, Univ. of Hawaii, Honolulu HI)

One of the most profound changes in our perspective of the solar system resulting from the first quarter century of planetary exploration by spacecraft has been the recognition that planets, including Earth, have been bombarded by cosmic projectiles for 4.5 aeons and continue to be bombarded today. Although the planetary cratering rate is much lower now than it was during the first 0.5 aeons, sizeable Earth-approaching asteroids and comets continue to hit the Earth at a rate that poses a finite risk to civilization. It is beside the point that the abundant evidence favoring an extraterrestrial impact as cause of the Cretaceous-Tertiary extinctions is still disputed by some scientists; independent research on asteroids, comets, and lunar and planetary crater populations proves inescapably that the Earth must encounter bodies roughly 10 km in diameter every 100 million years or so. Impacts of somewhat smaller bodies occur more frequently. The generation and maintenance of the size distribution of projectiles (grading down to mere boulders and dust) that accompanies the larger bodies is reasonably well understood both observationally and theoretically.

The evolution of this "planetary perspective" on impact cratering has been gradual over the last two decades; for planetary scientists, submerged in their topical research programs, the profundity of the new perspective may have been largely missed. However, despite a few prophetic comments about 40 years ago by such scientists as Ernst Opik and Ralph Baldwin and despite research about 30 years ago by Gene Shoemaker and others, until the mid-1960s impact cratering was still perceived as relevant chiefly to the Moon: as a geologic process, it was deemed a curiosity. It took explorations of Mars and Mercury by early Mariner spacecraft and of the outer solar system by the Voyagers to reveal the significance of asteroidal and cometary impacts in shaping the morphologies and even chemical compositions of the planets. Parallel observations of asteroids and comets, laboratory studies of Moon rocks and meteorites, and theoretical research on orbital dynamics and cosmogony have all helped planetary scientists to develop a perspective about extraterrestrial impacts that is remarkably robust, although still not fully appreciated by some practitioners of other scientific disciplines.

We wish to address an unsettling implication of the new perspective: the risk to human civilization. Serious scientific attention was given to this issue in July 1981 at a NASA-sponsored "Spacewatch Workshop" in Snowmass, Colorado; the workshop was partly motivated by the then-new Alvarez hypothesis concerning the K-T boundary. Some of the analyses in the never-published workshop report need to be updated in light of subsequent research. For example, studies of the K-T boundary and nuclear winter could improve on the older estimates of the environmental consequences of an impact of a given energy so that more reliable estimates could be made about the survivability of civilization. Nevertheless, the basic conclusion of the 1981 workshop still stands: the risk that civilization might be destroyed by impact with an as-yet-undiscovered asteroid or comet exceeds risk levels that are sometimes deemed unacceptable by modern societies in other contexts. Yet these impact risks have gone almost undiscussed and undebated.

The tentative quantitative assessment by some members of the 1981 workshop was that each year, civilization is threatened with destruction with

a probability of about 1 in 100,000 (i.e. about 1 chance in 2,000 during a person's lifetime). The estimate was extremely uncertain; the risk was viewed to be conceivably as high as 1 in 3,000 per year or conceivably as low as 1 in 10 million per year. Sticking with the nominal (and, again we stress, highly uncertain) estimate of 1 in 100,000, an individual's risk of dying in a civilization-destroying catastrophe is 5,000 times greater than the risk of dying from exposure to TCE at the EPA limit, 10 times greater than risk goals for regulations against Chernobyl-type nuclear power plant accidents, about twenty times the risk of death from a tornado, and 25 times less than the chance of dying in an auto accident.

The enormous spread in risk levels deemed by the public to be at the threshold of acceptability (for example, as contrasted by the lax regulation of cigarettes versus the strict regulation of nuclear power plants and some carcinogens) derives from a host of psychological factors that have been widely discussed in the risk assessment literature. Let us consider the impact hazard to civilization in this context. Slovic (1) shows that public fears of hazards (and hence pressure to regulate such hazards) are greatest for hazards that are uncontrollable, involuntary, fatal, "dreadful", globally catastrophic, and which have consequences that seem inequitable, especially if they affect future generations (examples of widely feared hazards are nuclear reactor accidents and nuclear war). Other factors that augment fear are perceptions that a hazard is newly recognized, due to unobservable agents, and difficult to assess or control. On all of these counts, we should expect the public to be more concerned about the impact hazard at the risk levels we have discussed than about other numerically equivalent risks. Basically, the probability of impact disaster is very low, but the consequences are unimaginably and horribly great.

The lack of public concern that has been expressed so far about this threat may reflect the limited publicity about it. However, there has been some technical and popular discussion of the issue, and the hazard has been treated in fairly accurate and realistic ways in some popular novels that describe collisions with comets or asteroids. Possibly the risk of impact is perceived to be so low that it crosses the threshold discussed by Starr and Whipple (2) of a risk being viewed as "negligible" or "impossible". If risks are lower than about one chance in a million, they are sometimes below a person's threshold of caring, no matter how bad the consequences. However, the 1981 workshop estimate of the probability of destruction of civilization due to cosmic impact was higher than one in a million.

The hazard due to impact could be dismissed as an unavoidable "act of God." But it is readily within modern astronomical capabilities to discover most of the potentially dangerous impactors, although only a tiny fraction are known today. Some thought has been given to ways to deflect an impacting asteroid, if discovered long enough in advance of impact. So society could undertake an amelioration of the hazard. We take no position on the appropriate response of society to this issue, except that we believe: (1) that sensible, informed public discussion of these issues is to be preferred to silence, and (2) there should be more research concerning the nature of this newly recognized hazard.

References: (1) Slovic, P. (1987) *Science*, 236, 280-285; (2) Starr, C. and Whipple, C. (1980) *Science*, 208, 1114-1119.