Letters

DOD's University Research Initiative

In Mark Crawford's article "R&D budgets: Congress leaves a parting gift" (News & Comment, 31 Oct., p. 536), the Department of Defense University Research Initiative (URI) was reported to be funded at \$8.75 million in fiscal year 1987 (FY 87). Actually, Congress appropriated \$35 million in FY 87 for URI, or \$8.75 million *each* for the three military Services and the Defense Advanced Research Projects Agency. DOD had requested \$50 million for URI in FY 87.

In fiscal year 1986 (FY 86), Congress appropriated \$100 million to begin the URI program, although Gramm-Rudman-Hollings and other reductions resulted in a FY 86 budget of approximately \$90 million. The FY 86 cuts, coupled with the FY 87 reduction, have resulted in a FY 86–87 total of \$125 million for URI, or \$25 million less than planned for the 2-year period. The recent congressional action will require us to adjust our expenditure rates for URI in FY 87.

RONALD L. KERBER
Research and Advanced Technology,
Office of the Under Secretary,
Department of Defense,
Washington, DC 20301

Comet Showers, Periodic Extinctions, and Iridium

In their investigation of iridium depositions over the period of 33 to 67 million years ago, Frank Kyte and John T. Wasson (Articles, 6 June, p. 1225) detected no anomalous iridium levels other than the known strong peak near the Cretaceous-Tertiary boundary. They conclude that there were no comet storms of the kind predicted by several theories (*1–4*). But their measurements were not sensitive enough to see comet storms of the kind expected, and their data do not provide evidence against the comet storm theories.

Kyte and Wasson did their analysis on the basis of a calculation of comet impact rates (*3*) in which we suggested that periodic comet storms could be triggered by a companion star to the sun, which we called "Nemesis." In our calculation, we took the number of comets in the region affected by Nemesis to be 10^{13}, on the basis of a model of Hills (*5*), and from this we deduced that typically 25 comets would hit the earth during a comet storm. But we also stated clearly that this number was uncertain by "one or two orders of magnitude," so the estimate of 25 should not be taken as a hard prediction. The Nemesis theory *allows* 25 or more impacts per storm, but it does not *require* that many.

An improved estimate for the number of comets in the hypothesized storms can be obtained by studying accurately dated impact craters. In our analysis of 11 impact craters on the earth (*6*), Alvarez and I found approximately one impact per comet storm, although because we could not include craters that have been inaccurately dated and because impacts in the oceans left no identifiable craters, this figure must be lower than the true average impact rate. In a later analysis that used 17 craters, Trefil and Raup (*7*) concluded that as few as a third of the impacts on their list may have contributed to the comet storm signal. From the fact that the periodic extinction data of Raup and Sepkoski (*8*) show few (if any) mass extinction cycles missing, we can conclude that the average cratering rate was one or more per cycle. From these considerations, and the discovery of two to three levels of microtektites near the Eocene-Oligocene boundary (*9*), I estimate the average number of impacts during recent comet storms to be in the range of one to four per storm. (We are including only impacts large enough to produce craters 10 kilometers in diameter or larger.) For further calculation here, I shall assume that the average number of impacts per storm is 2.5, midway in the allowed range. This is a factor of 10 less than the value of 25 per storm assumed by Kyte and Wasson. The duration of the comet storm has been estimated (*3, 10*) to be between 1 and 3 million years; I shall use the value of 2 million years. Then the average impact rate during the storm is about 1.5 per million years, but the true value could easily be a factor of 2 larger or smaller.

Of course, any one storm may have one or even zero impacts. If the average rate is 2.5 impacts per storm, then the probability of only one impact is $(2.5)\exp(-2.5) = 21\%$, and the probability of zero impacts is $\exp(-2.5) = 8\%$. Thus we can make no firm prediction that any particular storm will involve multiple impacts, although most storms will.

Kyte and Wasson state that the modern flux of long-period comets that could potentially hit the earth (those with perihelia of 1 astronomical unit or less) is 16 per year, out of which three are dynamically new, that is, entering the inner solar system for the first time. The remaining 13 are comets that have become trapped into relatively short-period orbits. We shall assume that the fraction of dynamically new comets during a comet storm is the same as now, 3/16. This is a plausible assumption, as the dynamics of trapping do not change during a storm.

Since the cratering data indicate that the number of impacts per storm is 2.5 rather than 25, the total number of comets intersecting the disk of the earth's orbit during a comet storm is not 2×10^9, as assumed by Kyte and Wasson, but closer to 2×10^8. Only 3/16 of these comets, that is, 4×10^7, are dynamically new. If the storm lasts for 2 million years, then the average flux of these new comets is 20 per year crossing the disk of the earth's orbit, a factor of 7 greater than the current flux of three per year. Likewise the number of comets trapped into stable orbits is a factor of 7 greater during the comet storm than it is now. The rate of impacts during a comet storm will be seven times larger than during the periods between storms; this is enough to give the significantly higher extinction rate of fossil families reported by Raup and Sepkoski (*8*).

Kyte and Wasson estimate that 20% of the iridium in their sample comes from cometary dust. An increase in this component by a factor of 7 would roughly double the total iridium concentration. In contrast, Kyte and Wasson estimate that the iridium concentration would increase by a factor of about 200. The difference in the two answers comes from several factors. The biggest effect comes from their assumption that there are 2×10^9 new comets in a storm, a value that we originally proposed as the midpoint in a range of values extending over four orders of magnitude, but which can now be ruled out by Earth impact crater data. We replace this value by the more realistic 4×10^7.

We can now compare our factor of 2 expected change in the iridium level to the variations observed by Kyte and Wasson. Their observed iridium concentration varies between 1.0 and 2.0 nanograms per gram in the period near the Eocene-Oligocene boundary, about 37 million years ago. It is not clear what causes the data to vary over this range; there seem to be systematic changes as well as statistical fluctuations. The variations could be due to changes in sedimentation rate, but they could also be due to variations in the influx rate of extraterrestrial material. The factor of 2 variation that they observe is consistent with the behavior expected from a comet storm according to our calculation, but the obvious systematic fluctuations in the background make a more definite conclusion impossible.

The continuum iridium level is five times lower near the Cretaceous-Tertiary iridium peak 66 million years ago, the other region where a comet storm is thought to have occurred. It is conceivable that the large