LETTERS TO THE EDITOR

COMMENTS ON "ESTIMATE OF THE HAZARDS TO A NUCLEAR REACTOR FROM THE RANDOM IMPACT OF METEORITES"

In estimating the probability of a nuclear power reactor being damaged or destroyed by a meteorite impact, Solomon et al.,[1] almost as an afterthought, include the case of damage to a coastal plant from a tsunami generated by a meteorite. They report that consideration of tsunamis increases the probability of damage to a coastal plant from 7×10^{-10} to 9×10^{-10} per plant year. We consider that the technique used, as described in Solomon et al.,[2] involving extrapolations from explosions, may not be applicable to the case of tsunamis, which involve enormous amounts of energy.

We believe that the present understanding of the mechanisms involved in tsunami generation, propagation, and coastal runup do not allow as exact an analysis as that performed for direct meteorite hits on a plant, or as that attempted for the tsunami case. Therefore, we attempt to bound the result by making use of some of the observed data from seismic tsunamis. The meteorite data given in Table I of Solomon et al.[2] are used, but their criteria of tsunami damage are simplified as follows: The plant is considered damaged if the coastal runup (what people actually observe) is greater than 20 ft. The plant is assumed to be along a straight coastline, i.e., the area enclosed in any circle centered at the plant is half land and half sea.

The problem is much simpler when attacked in this manner, as various authors (e.g., Iida[3,4] and Soloviev[5]) have studied the relationships between observed tsunami runup (both maximum and average), tsunami energy, and tsunami intensity. Because of the uncertainties in the tsunami runup to energy relation and in other relationships that we use, instead of trying to employ average or best values, we make an attempt to use extreme values and thus bracket the answer. From Soloviev,[5] an average tsunami runup of 20 ft would correspond to a tsunami intensity of 3.1 and an energy between 10^{22} and 10^{24} erg. Iida[4] found that for seismically induced tsunamis, the tsunami energy varied from one-tenth to one-hundredth of the seismic energy, with the larger tsunamis having a greater percentage of the seismic energy. Assuming that the conversion of meteorite energy to tsunami energy is of the same order of efficiency as is the conversion from seismic energy, then we find that the energy of the meteorite needed ranges from 10^{23} to 10^{26} erg. With a velocity range of from 37 000 to 290 000 ft/sec, the corresponding range

TABLE I

Tsunami height (ft)		20	
Tsunami intensity		3.1	
Tsunami energy (erg)	10^{22}		10^{24}
$\left(\frac{\text{Tsunami energy}}{\text{Meteorite energy}}\right)$	0.1		0.01
Meteorite energy (erg)	10^{23}		10^{26}
Meteorite velocity (10^3 ft/sec)	290		37
Meteorite weight (tons)	2800		173×10^6
Maximum district of impact (miles)		100	
Area of impact (ft^2)		4.379×10^{11}	
$\left(\frac{\text{Impact area}}{\text{U.S. area}}\right)$		4.17×10^{-3}	
Number of meteorites of at least wt W per year in U.S.	5×10^{-4}		4×10^{-7}
Number per year in impact area	2×10^{-6}		2×10^{-9}

in meteorite weight is 2800 to 173 million tons. The data used to relate tsunami height to energy were obtained primarily from tsunamis that originated within ~100 miles from the points where runup was observed. Therefore, we consider only meteorites impacting within 100 miles of the site (and in the sea) in this analysis. It should be evident that meteorites with higher energies can impact further from the site and still produce a 20-ft runup. It is of interest to point out that the Alaska earthquake of Mar. 1964, which resulted in tsunami amplitudes along the U.S. Pacific coast (at distances of from about 1200 to 2400 miles) ranging from <1 ft to over 29 at Crescent City, California, registered about 8.5 on the Richter scale, indicating an energy release of about 3.5×10^{24} erg. A meteorite of 10^{12} tons, with the minimum velocity of 37 000 ft/sec, has a kinetic energy of 5.8×10^{29} erg, which is 166 000 times as great as the energy release of the Alaskan earthquake. This meteorite has a probability of 1×10^{-9} per year for an area the size of the U.S., which is equivalent to a semicircular area with a radius of 1570 miles. This alone should cast doubt upon the very low probability reported by Solomon et al.[2]

By using the data from Table I of Solomon et al.,[2] the probability is calculated and found to range from $\sim 2 \times 10^{-6}$ to 2×10^{-9} per coastal plant year (Table I) for 20-ft tsunamis resulting from meteorite impacts within 100 miles of the plant. It is evident from the above discussion that:

1. We still have a long way to go before we can even feel confident that we know the order of magnitude of the probability of coastal plant damage due to meteorite-induced tsunamis. Our understanding of seismically produced tsunamis is limited, yet people have seen and recorded those. We know of no documented case, however, of a tsunami produced from a meteorite impact.

2. The value given by Solomon et al.[2] for tsunami damage to coastal plants is probably orders of magnitude too low. The one extreme value of 2×10^{-6} per year is probably too high. A reasonable guess would put the value at about 10^{-7} to 10^{-8}. This value is only for tsunamis generated within 100 miles of the site, and does not consider tsunamis generated by larger meteorites impacting further away.

Implicit in the above discussion was the assumption that the plant is located near an "average" coast. However, tsunami runup can be very sensitive to the local bathymetry and shoreline configuration. Some locations (such as Crescent City, California) can focus an incoming tsunami wave resulting in much higher than average runups, while other locations will diverge tsunami energy resulting in lower than average runups. We can therefore conclude that meteorites within the energy range given in Table I can generate 20-ft tsunamis at distances greater than 100 miles if local bathymetry and shoreline geometry are conducive to long-wave amplification.

The U.S. Nuclear Regulatory Commission looks carefully at all proposed coastal plants, even those in aseismic areas, to provide assurance that a plant will either be built in a location relatively insensitive to tsunamis or be designed to withstand such events. It is for this reason that we believe that the probability of meteoritic tsunami damage to a coastal nuclear plant is well below the design level of 10^{-7} per plant year. It is our position, however, that the probability is not as insignificant as indicated by Solomon et al.,[2] and thus the problem cannot be considered as closed.

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REFERENCES

1. K. A. SOLOMON, R. C. ERDMANN, T. E. HICKS, and D. OKRENT, "Estimate of the Hazards to a Nuclear Reactor from the Random Impact of Meteorites," UCLA-ENG-7426, University of California at Los Angeles (Mar. 1974).

2. K. A. SOLOMON, R. C. ERDMANN, and D. OKRENT, "Estimate of the Hazards to a Nuclear Reactor from the Random Impact of Meteorites," *Nucl. Technol.*, **25**, 68 (1975).

3. KUMIZI IIDA, "Magnitude and Energy of Earthquakes Accompanied by Tsunami, and Tsunami Energy," *J. Earth Sci., Nagoyi Univ.*, **6** (1958).

4. KUMIZI IIDA, "Magnitude, Energy, and Generation of Tsunamis, and Catalogue of Earthquakes Associated with Tsunamis," *Proc. Tsunami Mtgs. Associated with the 10th Pacific Science Congress*, Monograph No. 24, IUGG (1963).

5. S. L. SOLOVIEV, "Recurrence of Tsunamis in the Pacific," *Proc. Intern. Symp. Tsunamis and Tsunami Research* (1969).

ADDITIONAL COMMENTS ON "ESTIMATE OF THE HAZARDS TO A NUCLEAR REACTOR FROM THE RANDOM IMPACT OF METEORITES"

In a recent paper[1] it was estimated that potential serious damage to a reactor in the U.S. due to a postulated meteorite impact has a likelihood of $\sim 7 \times 10^{-9}$ per reactor per year, assuming a target area of 10^5 ft^2. At the end of the paper, the estimate was reported, with reference to a UCLA report,[2] that the likelihood of coastal reactor destruction due to a meteorite-induced sea wave was $\sim 2 \times 10^{-10}$ per coastal reactor per year.

The comments to this paper given by Fliegel and Hulman[3] take issue with the wave destruction likelihood cited above. They suggest that the probability of meteorite-induced wave damage is certainly $<10^{-7}$ per plant year for a coastal plant, but not as low as the 2×10^{-10} number cited earlier. In attempting to respond to the interesting points raised by Fliegel and Hulman, we first outline the method used in Ref. 2 and then give some further considerations of the wave-induced damage mechanism.

In Ref. 2, the reactor was assumed to be located one-tenth mile from shore and 30 ft above sea level on a