Anderson *et al.* Reply: In his Comment [1], Katz proposes that the anomalous acceleration [2] seen in the Pioneer 10/11 spacecraft [3] is due to anisotropic heat reflection off of the back of the spacecraft high-gain antennae, the heat coming from the radioactive thermal generators (RTGs).

Before launch the four RTGs delivered a total electrical power of 160 W (now ~70–80 W), from a total thermal fuel inventory of 2580 W (now ~2090 W). Presently ~2000 W of RTG heat must be dissipated. Only ~75 W of directed power could explain the anomaly [4]. Therefore, in principle, there is enough power to explain the anomaly this way. However, (1) the geometry of the spacecraft and (2) the radiation pattern preclude it.

Many years ago this problem was discussed with John W. Dyer, who was a Pioneer project engineer at NASA/ARC, and with James A. Van Allen. Below is at least a partial reconstruction of those discussions, which we wish to acknowledge.

(1) *Spacecraft geometry.*—The RTGs are located at the end of booms, and rotate about the craft in a plane that contains the approximate base of the antenna. From the RTGs the antenna is thus seen "edge on" and subtends a solid angle of ~1.5% of 4π steradians [5]. This already means the proposal could provide at most ~30 W. But there is more.

(2) *Radiation pattern.*—The above estimate is based on the assumption that the RTGs are spherical black bodies. But they are not. The main bodies of the RTGs are cylinders and they are grouped in two packages of two. Each package has the two cylinders end-to-end extending away from the antenna. Every RTG has six fins that go radially out from the cylinder. Thus, the fins are edge on to the antenna (the fins point perpendicular to the cylinder axes). Ignoring edge effects, this means that only 2.5% of the surface area of the RTGs is facing the antenna. Further, for better radiation from the fins, the Pioneer SNAP 19 RTGs had larger fins than the earlier test models, and the packages were insulated so that the end caps had lower temperatures and radiated less than the cylinder and/or fins [6]. As a result, the vast majority of the RTG heat is symmetrically radiated to space, unobscured by the antenna.

We conclude that Katz's proposal does not provide enough power and so cannot explain the Pioneer anomaly [7]. Independent of the above, we continue to search for a systematic origin of the effect.

A few weeks after our Letter [3] was accepted, we began using new JPL software (SIGMA) to reduce the Pioneer 10 Doppler data to 50-day averages of acceleration, extending from January 1987 to July 1998, over a distance interval from 40 to 69 AU.

Before mid-1990, the spacecraft rotation changed (slowed) by about $-(0.065\ \text{rev/day})/\text{day}$. Between mid-1990 and mid-1992, the spin deceleration increased to $-(0.4\ \text{rev/day})/\text{day}$. But after mid-1992 the spin rate remained approximately constant. In units of 10^{-8} cm/s^2, the mean acceleration levels obtained by SIGMA from the Doppler data in these periods are [2] (7.94 ± 0.11) before mid-1990, (8.39 ± 0.14) between mid-1990 and mid-1992, and (7.29 ± 0.17) after mid-1992. [Similar values (8.27 ± 0.05, 8.77 ± 0.04, and 7.76 ± 0.08) were obtained using CHASMP.] We detect no long-term deceleration changes from mid-1992 to mid-1998, and only two spin-related discontinuities over the entire data period.

Assume that the slowing of the spin rate was caused by spacecraft systems (perhaps gas leak changes) that also account for a few percent systematic effect. Then, excluding other biases (such as the radio beam decreasing the measured anomaly), we should adopt the post-1992 value as the most accurate measure of the anomalous Pioneer 10 acceleration.

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[1] J. I. Katz, preceding Comment, Phys. Rev. Lett. **83**, 1892 (1999); gr-qc/9809707.
[2] To understand the "constancy" [1] of the data, one must distinguish between $\sigma(x)$ (which can be large) and $\langle x \rangle$ (which yet can be quite precise; it goes as $N^{-1/2}$).
[3] J. D. Anderson *et al.,* Phys. Rev. Lett. **81**, 2858 (1998); see also gr-qc/9903024.
[4] Pioneer mass figures range from under 250 kg to over 315 kg. With credit and thanks to Randall Rathbun and Allen Parker of TRW, the launch weight was 295 kg (259 kg "dry weight" and 36 kg of hydrazine). V. J. Slabinski asked us about the mass.
[5] V. J. Slabinski independently obtained a figure of 1.6% for the solid angle.
[6] We thank S. Ted Christenbury of Teledyne-Brown for many helpful private communications and documents. See Teledyne Report No. IESD 2873-172, June, 1973.
[7] After the early eprint [1], Katz added Murphy's [this issue, Phys. Rev. Lett. **83**, 1890 (1999)] dissipated electrical power mechanism to his. We deal with that and Ulysses in our Reply [this issue, Phys. Rev. Lett. **83**, 1891 (1999)] to Murphy.

