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Gomory criticizes the \$2 billion per year spent on "space probes," arguing that support of individual investigators would be a better way to spend the money. As it happens, much of the NASA space science budget is spent on individuals. The 1991 directory of research projects for NASA's planetary geology and geophysics program, for example, shows that grants between \$40 000 and \$80 000 were made to 82 individual investigators from various universities, in addition to those from non-profit private organizations and government laboratories.

Gomory compares (unfavorably) the money spent on space probes with the total spent on individual investigators by NSF. But it should be remembered that NASA research support is, after all, an *additional* funding source for individual proposals.

The very term "space probes" suggests a misunderstanding of space research. The first discoveries made from space concerned the *Earth*: its shape, its gravity field and its radiation belts.¹ The first direct verification of plate movements was accomplished with satellite laser ranging (confirmed by very-long-baseline interferometry), an accomplishment simply impossible with conventional surveying methods. It should also be pointed out that NASA's "huge bill" has over the decades included development of space applications whose value is unquestioned: weather, communications and Earth resources satellites.

And true "space probes" have produced discoveries of fundamental importance, inherently unapproachable by Earth-bound research: the structure of the Big Bang, now expressed as the cosmic background radiation; radar mapping of an Earth-sized but cloud-covered planet; and many others often described in *PHYSICS TODAY*. These accomplishments are the result of teams of "individual investigators," to use Gomory's phrase. Finally, many "space probes" are hardly "megaprojects." The Cosmic Background Explorer, for example, would fit into a large pickup truck; Vanguard I was compared to a grapefruit; Sputnik 1, to a basketball.

A final point: Gomory suggests that "we need to ask some questions" about the NASA space budget. Congress spends months every year asking exactly such questions. The Space Exploration Initiative has just been abandoned because of Congressional opposition, and the Office of Exploration abolished. Furthermore, NASA research proposals are peer-

reviewed by outside scientists who also "ask some questions."

Reference

1. P. D. Lowman Jr, *Endeavour* **16**, 50 (1992).

PAUL D. LOWMAN JR
5/93 *Bowie, Maryland*

Ralph Gomory's article "Goals for the Federal Role in Science and Technology" was such a sensible and informative analysis of what the nation needs to do in this area that I sent a copy of it to my senators and representative in Congress, an act that I hope is consistent with the "fair use" principle of your copyright statement. If so, I urge that a person from each Congressional district in the country do the same thing.

WENDELL G. HOLLADAY
6/93 *Vanderbilt University
Nashville, Tennessee*

Scientists Supporting SSC Quoted Unfairly?

I find it interesting that in his letter in the March 1993 issue (page 13), Lon Hocker placed quotation marks around the word "scientists" when applying it to supporters of the SSC—the implication being, I suppose, that supporters of the SSC are not legitimate members of the scientific priesthood. Such tactics seem out of place in a purportedly rational debate.

As for the question of whether big or small science gives greater economic and technological payoffs, it seems largely irrelevant. Aside from members of Congress, few people try to justify the SSC in terms of spinoffs. The issue is, bluntly, Is it worth doing, and can we afford it? Hocker's judgment is no on both counts. Others may disagree without necessarily being scoundrels.

TODD BRUN
4/93 *California Institute of Technology
Pasadena, California*

CO₂'s Greenhouse Contribution Debated

Jocelyn Tomkin (December 1992, page 13) berates Alison Campbell (February 1992, page 15) for stating that "were it not for atmospheric CO₂, the mean temperature at the Earth's surface would be substantially below zero." Tomkin estimates that the complete removal of CO₂ from the atmosphere would decrease the surface temperature by only about 1 °C. Tomkin's estimate is essentially

based on the assumption that the magnitude of the decrease of the outgoing long-wave irradiance at the top of the atmosphere that would be produced by instantaneously doubling the CO₂ concentration is the same as that of the increase that would be produced by instantaneously removing the CO₂ entirely.

This is incorrect. At some wavelengths (near the center of the 15- μ m CO₂ band, for example) there is already so much CO₂ that the atmosphere is opaque over short distances, so adding more CO₂ is ineffective; an equivalent reduction has a much greater effect. Using a tested radiative transfer model,¹ one finds that for a midlatitude clear-sky atmosphere, doubling the CO₂ concentration from 350 to 700 parts per million by volume decreases the irradiance at the top of the atmosphere by 3.5 W/m²; removing the CO₂ entirely increases it by 32 W/m².

Corresponding estimates of the effect on the mean surface temperature of the Earth are much more complicated, as both Campbell and Tomkin say. But using a simple radiative convective model,¹ with no other change, one finds that doubling the CO₂ produces a 1.5 °C warming and removing it a 12 °C cooling. Including a simple relative humidity feedback (but no ice-albedo feedback) changes these values to 2.4 °C warming and 17 °C cooling.

Such a cooling would represent a huge change to the present climate, so 17 °C must be taken as a crude estimate. Including an ice-albedo feedback might well justify Campbell's statement. Tomkin's estimate of only 1 °C cooling is much too small, and his assertion that Campbell had overlooked the importance of water vapor is unjustified.

We were sorry to learn that more than half of Tomkin's professional colleagues thought CO₂ rather than H₂O the major greenhouse gas. Meteorologists have become accustomed to the fact that most physicists have little interest in atmospheric processes. Surely not astronomers too?

Reference

1. K. P. Shine, A. Sinha, *Nature* **354**, 382 (1991).

HENRY CHARNOCK
3/93 *University of Southampton
Southampton, UK*
KEITH P. SHINE
*University of Reading
Reading, UK*

Alison Campbell may be mistaken in her assertion that global mean surface temperature would be below