Letters

Retraction of Data

We write this letter to inform the *Science* readership about information pertinent to a Research Article entitled "Identification of a T helper cell–derived lymphokine that activates resting T lymphocytes" by Claudio Milanese, Neil E. Richardson, and Ellis L. Reinherz which appeared in the 7 March 1986 issue of *Science* (**231**, 1118). In our view, those biological data are not reproducible and are incorrect, and we wish, therefore, to retract the data and the conclusions based on them. To our knowledge, there is no 12-kilodalton lymphokine with the functional attributes described in that publication. A second paper on this lymphokine ("A lymphokine that activates the cytolytic program of both cytotoxic T lymphocyte and natural killer clones" by C. Milanese, R. F. Siliciano, R. E. Schmidt, J. Ritz, N. E. Richardson, and E. L. Reinherz published in the *Journal of Experimental Medicine* [**163**, 1583 (1986)] is similarly being withdrawn. We extend our apologies to the scientific community and trust that certain misinformation presented in that article can be rectified by publication of this retraction letter.

Claudio Milanese*
Neil E. Richardson
Ellis L. Reinherz
Laboratory of Immunobiology, Dana-Farber Cancer Institute, 44 Binney Street, Boston, MA 02115 and *Harvard Medical School, Boston, MA 02115*

*Present address: Turin, Italy 10125

Ballistic Missile Defense: Cost of Space-Based Laser

Having demonstrated by careful calculations that the "Ballistic Defense System . . . would be unable to maintain its effectiveness at less cost than it would take to proliferate the ballistic missiles necessary to overcome it," George Field and David Spergel (Articles, 21 Mar., p. 1387) conclude that such a system, which is expected to cost hundreds of billions of dollars, will therefore not satisfy President Reagan's own requirement for an "effective strategic defense."

Should the objective of the President's policy be not, as is generally assumed, the maintenance of military balance between the Soviet Union and the United States, but rather the attainment of military superiority over an adversary—whose total economic potential (as measured, say, by its gross national product) is commonly recognized to be inferior to that of the United States—building up strategic defense capabilities costing more than the offensive weapons they will be able to destroy might up to a point still make sense.

As long as the armaments race is confined—as it has been up to now—to the acquisition by each side of the capability to inflict greater and greater damage on the other side, it can be expected to reach an upper limit when both powers, having accumulated enough offensive weapons to be capable of utterly destroying each other, will not dare to use them but, on the other hand, will also have no reason—at least no military reason—to continue the arms race. Since technological advances increase rapidly the "size of the bang" that can be produced for a buck, that limit will be—if it has not yet already been—reached, long before the economically weaker side finds itself unable to continue to transfer its economic resources from civilian to military uses.

An arms race involving the competitive buildup not only of offensive but also of defensive weapons cannot, however, end in a peaceful stalemate of this kind. By allocating more of its remaining economic resources—as long as they are available—to production of either one or the other kind of weapon, each side will always be able to either catch up with or overtake, as the case may be, its adversary. As long as the ratio of the total economic potential, say, the gross national product, of the stronger to that of the weaker power exceeds the "cost-exchange ratio" as defined by Field and Spergel, that is, the cost of producing an additional missile compared with the cost of destroying it, there can be no stalemate ceiling to such an all out arms race.

Starting from a position of approximate military balance, the economically stronger power will in this case be ultimately able to begin to translate its economic superiority into a clear-cut military superiority over the economically weaker power, unless, of course, just before that point has been reached the latter chooses, in desperation, to strike first.

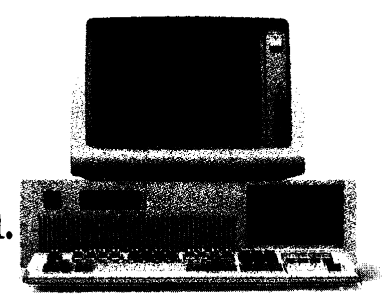
A decision to do so might be said to be irrational, but anyone familiar with past history, not only of the Soviet Union but also of other countries, will concede that the possibility of such a tragic outcome should not be discounted lightly.

A very different picture of the ultimate outcome of the ongoing arms race was presented with the initial announcement of a Strategic Defense Initiative: a picture of both the United States and the Soviet Union basking in the safety of perfect antiballistic missile shields. Since the degree of protection provided even by perfect, large complex physical systems cannot possibly be expected to exceed, say 99 or 98%, both sides will be tempted, even forced, to raise the number of nuclear missiles from the thousands that they now possess to tens and even hundreds of thousands. The rosy picture described above is a mirage.

WASSILY LEONTIEF
Institute for Economic Analysis,
New York University,
New York, NY 10003

The article by Field and Spergel on the cost-exchange ratio (CER) of space-based laser defense systems is a welcome precedent in the whole Strategic Defense Initiative (SDI), or "Star Wars," debate because its appearance in an unclassified peer-reviewed journal allows for discussion, criticism, and analysis in the normal scientific mode. The authors focus on a crucial parameter—CER, the cost of destroying a missile divided by the cost of a missile. If one assumes both sides have access to comparable technologies, when the CER is not equal to 1 the system economics tend to destabilize the total number of *offensive* missiles, decreasing them when the CER is less than 1 (good), and increasing them when the CER is greater than 1 (bad). These criteria are based on the argument that replacement of (population-destroying) offensive nuclear missiles by defensive (missile-destroying) deterrents is a desirable path toward international security, while an accelerated offensive arms race is not, and that a transition from an offense- to a defense-dominated world requires a CER of less than 1.

However, we believe the conclusion by Field and Spergel that the CER is "likely to exceed unity for the proposed (space-based laser) system, even if the defense achieves shorter targeting times, while the offense fails to achieve shorter boost-phase durations" is incorrect, as is the authors' contention that they "chose lower limits to costs to the defense and upper limits to costs to the offense." Their clear implication is that even when one attributes the most favorable tech-



nological developments to a laser defense system, its CER is greater than 1.

This is simply not true, as the following example illustrates: Field and Spergel assume an infrared (ir) laser wavelength (λ_{ir}) of approximately 2.7 micrometers (μm) and a mirror with a diameter (D_{ir}) of approximately 10 meters. These values are characteristic of deuterium-fluoride–hydrogen-fluoride (DF-HF) chemical gasdynamic lasers (*1*), but are surely not optimum for space-based laser defense systems. Because beam brightness is proportional to $(\lambda/D)^2$ a shorter wavelength would permit a smaller mirror, lighter weight, and less cost. For example, high-power rare gas-halogen excimer lasers now under development (*2*) operate in the near ultraviolet with a λ of approximately 0.3 μm. For the same beam brightness a mirror diameter of approximately $(\lambda D_{ir})/\lambda_{ir}$, about 1.1 meters, is needed, less than half the 2.4-meter aperture of the Hubble Space Telescope (HST). At constant brightness the number of missiles destroyed per laser platform (***n***) (table 1 of Field and Spergel) is unaffected. The number of attacking missiles (***m***) is approximately 1400, and laser platforms ($k = n/m$) are also unaffected. But it follows from equation 17 of Field and Spergel that the cost of destroying a missile, and therefore the CER,

Table 1.

Targeting time t_T (sec)	Duration of boost phase t_B (sec)		
	50	100	200
0.1	0.22	0.13	0.075
1.0	0.40	0.24	0.14
10	1.15	0.68	0.40

is proportional to $D^{1.68}$. Accordingly, CER/CER$_{ir}$ is equal to $(D/D_{ir})^{1.68}$, or about 0.025, where CER$_{ir}$ is the cost-exchange ratio of a DF-HF laser system. Simple scaling then gives the CER's of an excimer space-based laser system, which are directly comparable to those of Field and Spergel (Table 1).

This looks more promising than the version in the article and conveys a much more optimistic prospect for space-based laser defense. The authors indicate that "the defense could reduce [CER] by increasing brightness." For the excimer laser brightness goes up by a factor of approximately 100 when the mirror is kept at the nominal 10-meter aperture. However, this imposes more stringent constraints on the mirror surface accuracy and in any event is not a particularly good strategy compared with using smaller mirrors. As is implicit in equation 4 of Field and Spergel, at constant targeting time t_T and boost-phase time t_B, decreasing the dwell time t_D by using a brighter source reaches a point of diminishing returns in terms of missiles destroyed. In other words, the significant potential for decreasing the CER of a space-based laser defense by exploiting short wavelengths is not only obscure in the article by Field and Spergel, but its possible improving effect on performance is not put to optimum use. This does not mean that operational short-wavelength, high-power lasers appropriate for the job at hand actually exist, but that if they could be developed at the efficiency, mass-to-orbit, and power required, the CER of space-based laser defense systems would improve enormously. The limitation here is one of technological development, not an unbeatable law of nature like the diffraction limit.

Another problem with the analysis of Field and Spergel is the cost-estimation approach used, which is both favorable and unfavorable to the defense, in different degrees. It is favorable because it attributes all costs to the optical system and unfavorable because in computing these costs the overpriced HST program is used to extrapolate to large SDI systems, which could incorporate many different types of economies of scale. (In fairness, the authors recognize this is a problem.) The SDI cost-effectiveness criteria, as put perhaps somewhat more carefully by arms controller Paul Nitze (*3*) than in President Reagan's remarks, is that before it is deployed a strategic defense must be certain to survive attack and be "cost effective *at the margin*" [emphasis ours]. Field and Spergel have modeled the marginal cost aspect by scaling the cost per platform by $k^{-0.23}$ in their equation 16, where k is the number of platforms. However, their baseline cost per unit mass for the 10-meter mirror case is about $\$(3.59 \times 10^9)/$ (191,000 kilograms), or \$18,800 per kilogram. This is at the very highest end of specific costs for space vehicles, an order of magnitude above operational military aircraft and two orders of magnitude above civilian aircraft with large production runs (*4*). It is some six times higher than current space shuttle transportation costs of \$3000 per kilogram, so it cannot be argued that it is transportation-dominated. If the production costs were cut to \$2000 per kilogram and space transportation costs were cut to \$300 per kilogram (*5*), the theoretical first unit cost would drop by a factor (2300/18800), or about 0.12, and the CER's for the excimer laser system would be as shown in Table 2. At this point, a nonnuclear laser defense begins to look so good that, even

Table 2.

Targeting time t_T (sec)	Duration of boost phase t_B (sec)		
	50	100	200
0.1	0.027	0.016	0.0092
1.0	0.049	0.029	0.017
10	0.14	0.083	0.049

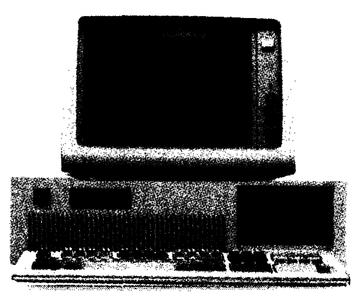
when one takes into account the various assumptions listed by Field and Spergel at the end of their article that, if violated, would increase the CER, the reasonable conclusions are that the issue remains open, that technological developments could well create a breakout in which the system would be viable, and that a prima facie case against space-based laser defense is simply not there.

An overriding consideration in assessing strategic defense systems might be pondered by those scientists and engineers who have opted to boycott the SDI program on grounds that it will necessarily destabilize, in an undesirable direction, the strategic arms race: The likely alternative to SDI is not the dismantling of Mutual Assured Destruction, but its institutionalization into the indefinite future. One thing that has been learned from 40 years of bilateral arms control negotiations by U.S. and Soviet administrations is that strategic offensive weapons, once acquired, are almost impossible to get rid of. This is partly because they are an extremely cost-effective technology in the threat-counterthreat dynamics of the arms race (*6*). While we have grown up with the system, it is potentially devastating to the planet (*7*). It is still not certain that an SDI system can be found that will "work" in the sense of providing a credible first-strike shield for populations on both sides behind which they can reduce and eventually eliminate offensive strategic weapons, but there is a real possibility of success and a real danger in giving up too soon.

MARTIN I. HOFFERT
GABRIEL MILLER
Department of Applied Science, New York University, New York, NY 10003

REFERENCES AND NOTES

1. R. W. F. Gross and D. J. Spenser, in *Handbook of Chemical Lasers*, R. W. F. Gross and J. F. Bott, Eds. (Wiley, New York, 1976), pp. 619–666; W. R. Warren, in *Gas Flow and Chemical Lasers*, J. F. Wendt, Ed. (Hemisphere, New York, 1979), pp. 151–167.
2. C. A. Brau, in *Excimer Lasers*, C. K. Rhodes, Ed. (Springer-Verlag, New York, 1979), pp. 87–133. True continuous wave operation of excimer lasers is difficult to obtain because instabilities in the ionized gas limit individual pulses to about 1 microsecond [R. S. Taylor and K. E. Leopold, *Appl. Phys. Lett.* 47, 81 (1985)]. However, high-repetition rate excimer lasers with gas recycling can be employed [C.



P. Christensen, in *High Power Lasers and Applications*, K. L. Kompa and H. Walther, Eds. (Springer-Verlag, New York, 1978), pp. 45–48]. Given a "burst mode" onboard power supply to pump the excimer states there is no apparent reason why 25 megawatts mean output power levels of more than 100 seconds, comparable to those of DF-HF chemical lasers at 2.7 μm assumed by Field and Spergel, could not be obtained at a λ of approximately 0.3 μm in space-based systems. If the power supply were a high-power density fuel cell, the system would in effect be a short-wavelength chemical laser with an intermediate electrical conversion step.
3. *Time*, 11 March 1985, p. 17.
4. F. R. Eldridge, *Wind Machines* (Van Nostrand Reinhold, New York, 1980), p. 144.
5. L. Bekey and J. E. Naugle, *Just Over the Horizon in Space Astronautics and Aeronautics* (National Aeronautics and Space Administration, Washington, DC, 1980). This technical assessment projected substantial cost reductions for post–space shuttle launch vehicle technologies on the basis of energy requirements: "The Shuttle will not do better than $1000 to transport one kilogram to orbit, compared to only $5 to fly one kilogram in an airliner from Los Angeles to New York, although the energy requirements are the same." These authors expected that fully reusable vehicles and other transportation systems would reduce the costs of space transportation "by at least two orders of magnitude." More recently, aerospace planes with airbreathing propulsion systems based on supersonic combustion technology have been seriously proposed for flying directly into orbit with reusable components at far below present launch vehicle costs. A hypersonic transport airliner version, dubbed the Orient Express, has received preliminary development funding by the present Administration.
6. L. F. Richardson, *Arms and Security* (Homewood, Pittsburgh, PA, 1919/1960). Richardson's arms race models are expressed as coupled rate equations for stocks of military goods accumulating in a given nation and that of its rival. The stock flow interaction is such that if the perceived difference is too large or too small, a nation alters its decisions accordingly. For plausible values of parameters a runaway arms race is usually inevitable given an atmosphere of mutual distrust (modeled as perceived tension indices), which is limited ultimately by budgetary constraints from the nonmilitary sector of the economies. Contemporary applications of Richardson modeling to the U.S./Soviet strategic arms situation are discussed by M. D. Ward [*Am. Pol. Sci. Rev.* 78, 297 (1984); *Confl. Manage. Peace Sci.* 7, 1 (1984)].
7. J. Schell, *The Fate of the Earth* (Knopf, New York, 1982).

Response: Hoffert and Miller state that infrared lasers are not optimum, that ultraviolet lasers will result in the reduced cost-exchange ratios (CER's) in their table 1, and that further reductions in costs will be possible (their table 2), so that "a nonnuclear laser defense begins to look so good . . . that a *prima facie* case against [it] is simply not there."

Infrared lasers indeed may not be optimum. We stated in our article (p. 1389) that shorter wavelength lasers have the potential to decrease the CER. Our analysis was restricted to infrared lasers; as some readers may not have understood this, we regret that the word "infrared" was not included in the title.

We agree that shorter wavelength (0.3 micrometer) lasers in space could result in lower costs. Hoffert and Miller propose a high power, rare gas–halogen excimer laser for this application. Noting that suitable such lasers do not now exist, they suggest that lasers of the "efficiency, mass-to-orbit, and power required" can be developed. This seems doubtful (*1, 2*). Gerold Yonas (*1*), until recently Chief Scientist of the Strategic Defense Initiative Organization, has stated that the "efficiency [of excimer lasers] is so low and generating apparatus is so bulky (even though the optics could be a reasonable size) it is unlikely that they and their fuel supply could be lifted into space in cost effective ways."

Hoffert and Miller scale the cost of infrared laser optics down by a factor of 40 because of the smaller mirror size. However, one cannot simply carry this factor directly over to the CER, because with such a low cost for the optical system alone, other components of a laser platform, which we neglected in order to be conservative in our article, including the generator of the laser beam, the power supply, and systems for pointing, acquisition, and tracking, would probably dominate the cost, particularly in view of Yonas' comments. The CER's in table 1 of Hoffert and Miller are therefore unreliable pending a more detailed analysis of a space-based excimer laser system.