letters

Making nuclear weapons obsolete

I appreciate the many kind words Richard Garwin had for *How To Make Nuclear Weapons Obsolete* in his recent review (December, page 75). But I must take issue with his allegations of technical errors, as well as his strategic and political perceptions of the US and the USSR.

▶ *The submarine deterrent.* Garwin says the Strategic Defense Initiative is unnecessary because our ballistic-missile submarines are a sufficient retaliatory force, and he mentions the report by the Scowcroft Commission on strategic forces in support of that view. His statement is directly contradicted by the Scowcroft report itself, which cites the "high priority" assigned by the Soviets to antisubmarine warfare, and which concludes that "over the long run it would be unwise to rely so heavily on submarines as our only ballistic-missile force that a Soviet breakthrough in antisubmarine warfare could not be offset by other strategic systems." This is also the technical assessment rendered in *How To Make Nuclear Weapons Obsolete.*

Several promising *nonacoustic* lines of research already exist for the detection of submerged submarines. Most promising is the measurement of disturbances in the sea surface using satellite-based synthetic aperture radars. Thermal "wakes" produced by reactor heat and by the upward displacement of cold water from depths to the surface are also possibilities. At some point in the future, possibly in the next decade, ballistic-missile submarines will lose their invisibility. As a Pentagon nuclear planner said[1] recently, "It is a matter of time before our confidence in the invulnerability of the submarine leg is degraded." The question is not whether but when.

▶ *Countermeasures.* The most interesting technical issues relate to Garwin's claim that countermeasures are simpler and cheaper than the defense itself. The Soviet government has indicated by its actions that this claim is untrue. While denouncing the US for proceeding with SDI research, the USSR is, according to CIA Congressional testimony, allotting no less than $40 billion a year to strategic defense, of which about $25 billion is for SDI-type missile defense. This is 10 times the amount likely to be appropriated by Congress for SDI in fiscal year 1986. If the Soviets thought that their countermeasures to our defense would be cheap and effective, as Garwin says they are, they would encourage us to go ahead and waste our money, knowing they could penetrate our defenses at any time. And Mikhail Gorbachev would not allow his own defense establishment to spend all those tens of billions of rubles on a massive Soviet SDI if he thought it to be a waste of money.

It is clear that the Soviets do not agree with Garwin's judgment on the matter of countermeasures.

▶ *Shielding an SS-18.* How much payload does that cost the Soviets? Garwin says 8 tons of shielding spread over the skin of an SS-18 reduce its payload by the weight of one warhead, which is roughly 350 kilograms. It can be calculated from the rocket equation and the areas, burnout velocities and weights (empty and fueled) of the SS-18 stages and bus that 8 tons of shielding reduces the payload of the SS-18 by approximately 4 tons, or more than 10 times Garwin's estimate. This would wipe out the entire SS-18 payload of ten warheads. If the Soviets felt they had to shield their ICBMs in this way to protect them, that would indeed be an effective response from American scientists to the President's call for means of making these missiles "impotent and obsolete."

The error in Garwin's calculation on loss of payload is, as noted, roughly a factor of 10. A factor of 2 would not matter very much in a discussion of technical feasibility, but orders of magnitude count, and in the technical analyses of SDI published by the Union of Concerned Scientists and by Garwin, the important errors are often by orders of magnitude. I have commented elsewhere[2] on the fact that in calculating the number of satellites needed to defend the United States against the "standard" Soviet threat (simultaneous launch of all ICBMs in

the present Soviet arsenal), the UCS and Garwin changed their results from 2400 satellites in the orginal report to 79 satellites in Garwin's latest publication. Garwin's most recent estimate agrees[3] with the accepted result for this problem, which is roughly 100 satellites. The correction here is a factor of 30.

In discussions of the neutral-particle beam as a booster and warhead killer, the UCS report stated that an accelerator weighing 40 000 tons must be put into orbit. The correct weight for this accelerator is roughly 25 tons—an error of a factor of 1600. In Garwin's discussions of the fast-burn Midgetman as a Soviet countermeasure, he set the cost at $5 million per warhead initially,[4] and then raised it to $10 million per warhead.[5] What is a realistic estimate for the cost of a fast-burn booster? Major General Gordon Fornell, who directs both the MX and the Midgetman programs for the Air Force, says[1] an "ordinary" Midgetman will cost at least $60 million per warhead deployed, and James Fletcher has told me a fast-burn booster could easily cost twice as much as the ordinary variety, or, in very round numbers, at least $100 million per warhead—again an order of magnitude above Garwin's figure.

The effect of Garwin's absurdly low estimate for the cost of the fast-burn booster is, of course, to make this proposed countermeasure seem much more attractive to the Soviets than it actually is. There are other problems with the fast-burn booster as a Soviet countermeasure, such as the fact that after the booster burns out, the bus cannot deploy its warheads immediately but must rise above the atmosphere first. That lengthens the window of opportunity for our attack by a minute or more, and makes a wasted effort out of the whole exercise of throwing away the existing fourth- and fifth-generation Soviet arsenals and replacing them with an arsenal of fast-burn boosters. But even if the Soviets thought they could benefit from doing that, they would find it to be a very expensive proposition—as much as a trillion dollars for 10 000 warheads.

It is interesting to note, finally, that these order-of-magnitude errors are always in one direction—to make the proposed defenses against a Soviet nuclear attack seem costly and ineffective. The errors are never in a direction that would make these defenses seem cheaper or more effective than they really are.

▶ *Diffraction effects.* Garwin quotes a passage from *How To Make Nuclear Weapons Obsolete* to suggest that its treatment of laser beams in space neglects the effects of diffraction. But the quoted passage is followed immediately by four pages of discussion of diffraction and its consequences for a laser defense, which qualitatively explain the effect of diffraction on the width of a beam, the requirement it creates for large mirrors in space, the cost of making these large mirrors and so on.

This is a fine example of a quotation lifted out of context to make the author seem to say the opposite of what has actually been said. It is a device employed by hostile reviewers in the lay press, but one does not expect such practices in the pages of PHYSICS TODAY.

▶ *Vulnerability of satellites.* Garwin quotes Edward Teller on this point. But Teller must have changed his mind recently, because in the 28 October 1985 issue of *Insight* magazine he stated that space-based defenses can be made survivable by hardening or armoring; by proliferation or the deployment of "sleepers," in other words, silent spares activated if an operational satellite is destroyed; and by decoy satellites. To these three mechanisms of defense proposed by Teller can be added maneuverability (the ability to step out of the path of the intercepting missile or warhead) and gunnery (the ability to shoot back at the attacker).

Employed together, these defensive strategies can give satellites a high measure of survivability. It is feasible to employ them simultaneously because none interferes with the functioning of the satellite. Shielding, guns, rocket fuel for maneuvering, and decoys—all can be added with no penalty to the defense, except for the cost of putting the added weight into orbit.

On that score, new developments in rocket design promise to bring down the cost of sending mass into orbit by a factor of 10, and an even more exciting development—the transatmospheric vehicle using supersonic combustion ramjets for propulsion—may bring the cost of sending mass into orbit down by a factor of 100 relative to shuttle prices. That means tens of dollars a pound rather than thousands of dollars a pound. Such reductions irrevocably tilt the balance of cost in favor of the defense over the offense and make a survivable space-based defense an entirely practical objective.

Satellites have been very vulnerable up to now because it is cheaper to build them that way and no one has been shooting at them yet. But the satellites planned for the 1990s are being designed very differently. Armored, proliferated, defended, decoyed and maneuverable, they could constitute a highly survivable and robust defensive system.

▶ *Arms control.* Finally, Garwin objects strongly to the proposition that

with a missile defense in place on both sides the path will be cleared to parallel and simultaneous reductions by the US and USSR in the numbers of their offensive weapons. This is the position of our government's negotiators in Geneva, and it seems to me to be realistic. If each side has a defense that is 90% effective, meaning only one in ten warheads can reach its target, it will certainly seem less attractive to the defense planner to continue putting defense dollars or rubles into these very expensive weapons, and he may well look to other ways of spending his money. After all, if it became known that 90% of our B1-B bombers and their payloads would be shot down on approaching Soviet air space, Senator Sam Nunn would not be likely to get up on the floor of the Senate to say, "Let's build ten times as many B1-Bs to overwhelm this defense." He would be more likely to say, "Let's scrap this ineffective weapons system and find a better way of spending our defense dollars."

References

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2. R. Jastrow, J. Int. Affairs **39**, no. 1, 45 (1985).
3. R. Garwin, Nature **315**, 286 (1985).
4. H. A. Bethe, R. L. Garwin, K. Gottfried, H. W. Kendall, C. Sagan, V. F. Weisskopf, Commentary, March 1985, p. 6.
5. Transcript of Hearings, Defense Subcommittee of Senate Appropriations Committee, 22 April 1985, p. 28.

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Noncrystalline semiconductors

The recent letter of William Paul and Henry Ehrenreich (August, page 13) is an ironic example of how an attempt to provide "a historical perspective" about an important field can itself "perpetuate and even extend some prevalent misconceptions." Rather than clarifying the single sentence by Hellmut Fritzsche in his review (October 1984, page 34), the long narrative of Paul and Ehrenreich, while attempting to be factual, actually serves to distort the situation in a major way.

Amorphous silicon alloys are important because they are able to mimic the semiconducting properties of crystalline silicon, while possessing the additional quality that they can be prepared rapidly over large areas in a thin-film geometry. Beyond the economic benefits, however, the possibility of controlled alloying of the amorphous materials promises greater flexibility and consequently improved device performance using heterojunction configurations. As just one example, multiple-junction amorphous solar cells are now outperforming[1] single-junction cells. This accomplishment required several steps:

- ▶ a sharp reduction in the defect approximation so that the density of states near the Fermi energy is less than approximately 10^{16} cm^{-3} eV^{-1}
- ▶ the ability to modulate the energy gap by alloying while retaining low defect concentrations
- ▶ the development of materials that do not degrade under device operating conditions.

If any of these problems were to remain unsolved, interest in amorphous silicon alloys would soon go the way of that in pure amorphous silicon, which was investigated extensively in the early seventies but has not been discussed recently because the defect concentration could not be lowered to electronically acceptable levels.

Interest in the field of tetrahedral amorphous semiconductors was sustained by the accidental discovery of hydrogenated amorphous silicon, as detailed by Paul and Ehrenreich, which was a major step towards achieving the first of the previously mentioned goals. However, some residual defects always remain in this material, and it degrades when exposed to sunlight[2] to the point where its use in devices becomes questionable. Furthermore, attempts[3] to make high-quality hydrogenated amorphous silicon–germanium alloys for band-gap modulation failed. Obviously, a new concept was essential.

It is now clear that the deliberate development of fluorinated amorphous materials[4] led to the simultaneous accomplishment of all three goals. The chemical explanation of the problem of the origin of the density of states in the silicon–germanium alloys and of fluorine's role in solving this crucial problem was given[1,5,6] in several papers. Subhendu Guha (Energy Conversion Devices), in an invited paper at the most recent International Conference on Amorphous and Liquid Semiconductors, just held in Rome (2–6 September 1985), not only documented[7] the stability of devices based on these materials but also reported experimental results showing the low density of defect states so necessary to making these materials useful. He described as well the development of semiconductor-grade alloys of different band gaps. That fluorine plays the suggested role has been independently confirmed by a host of investigators, as is evident from the papers presented at the same international conference. At least 14 papers at this