tion of natural gas prices at artificially low levels that makes solar heating less attractive. The government agencies authorized to promote solar heating technologies—ERDA and HUD—have no authority over natural gas regulation.

6. R. Gilpin, *Technology, Economic Growth, and International Competitiveness*, prepared for the Subcommittee on Economic Growth of the Joint Economic Committee, Congress of the United States (Government Printing Office, Washington, D.C., 1975); G. Eads, *Res. Policy* **3**, 2 (1974); _____ and R. Nelson, *Publ. Policy* **19**, 405 (1971).
7. See, for example, P. Berman and M. W. McLaughlin, *Federal Programs Supporting Educational Change*, vol. 1, *A Model of Educational Change* (The Rand Corporation, R-1589/1-HEW, Santa Monica, Calif., 1974).
8. Office of Management and Budget, *Special Analyses: Budget of the United States Government: Fiscal Year 1977* (Government Printing Office, Washington, D.C., 1976), p. 277.
9. Energy Research and Development Administration, *A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, 1976* (Government Printing Office, ERDA 76-1, Washington, D.C., 1976), vol. 2; Congressional Budget Office, *Energy Research: Alternative Strategies for Development of New Energy Technologies and Their Implications for the Federal Budget* (Background Paper No. 10, Washington, D.C., 15 July 1976).
10. Twenty-four observations clearly do not allow us to test for the statistical significance of our results. We chose to conduct in-depth case studies rather than analyze a larger sample randomly drawn from the 41 agency programs for three principal reasons. First, the lack of previous analysis provided little guidance for choosing a priori the critical variables for investigation. In-depth studies were necessary to construct a conceptual framework for the subsequent analysis of other cases. Second, a few agency programs, such as the Environmental Protection Agency's programs for air and water pollution control, contain large numbers of demonstrations with similar characteristics. A random sample of projects would bias the results toward these particular programs; on the other hand, a sample of programs would not provide enough observations to yield statistically significant results. Finally, the goal of the analysis was not to determine how many federal demonstrations succeed and fail, but to find attributes of demonstrations that are associated with success and failure. We thus selected cases to provide variance in the dependent variables—the measures of success.

    The 41 agency programs containing demonstrations are listed in *Analysis of Federally Funded Demonstration Projects: Final Report* (The Rand Corporation, R-1926-DOC, Santa Monica, Calif., 1976) along with descriptions of the 24 projects selected for analysis. See also *Analysis of Federally Funded Demonstration Projects: Supporting Case Studies* (R-1927-DOC, 1976) for the full case studies of the 15 demonstrations analyzed in the first and second rounds (Table 1).
11. Measurement of diffusion success involves two major difficulties. Ideally, diffusion success would measure the difference between the actual rate of diffusion and that which would have occurred without the demonstration. However, existing data on industry adoption rates are too fragmentary to make baseline comparisons. A second problem arises because the projects studied vary greatly in their observable histories. Many demonstration projects were begun in the past 10 years—a time that may be too short to expect significant diffusion results. Consequently, a project we judge today to have resulted in "little or no" diffusion may in tomorrow's hindsight be viewed as a significant milestone. Operation Breakthrough is a possible example of this sort. Our definitions of the levels of diffusion success partly cope with this problem by focusing on the diffusion process rather than simply counting the number of adoptions that have taken place. Consequently, even if the absolute number of adoptions is low, we can still characterize diffusion as "significant" if the process is self-sustaining. In such cases we have made our best judgments about prospects for diffusion, based upon our interviews with potential adopters and others familiar with the demonstration.
12. Figures 2 and 3 include 21 observations from the 24 projects because (i) the Dial-A-Ride demonstration is split into two modes of vehicle dispatching—manual and computer—for purposes of analysis because outcomes differed for the two modes; and (ii) four cases are excluded: the synthetic fuels program, the automatic vehicle identification project, and the REAM gun project, all of which are in the field test or pilot stage rather than in the demonstration stage; and the NASA/FAA Refan project because it is a regulation-oriented demonstration for which diffusion success is an inappropriate measure.
13. The "high," "medium," and "low" rankings of technological uncertainty correspond to other ordinal scales derived for military systems that use such measures as the extent to which the same technology has been successfully used in other applications, the number of components that must be assembled into the new system, and the scale-up required. See, for example, the discussion of "technological advance ratings" by R. L. Perry, G. K. Smith, A. J. Harman, and S. Henrichsen [*System Acquisition Strategies* (The Rand Corporation, R-733-PR/ARPA, Santa Monica, Calif., 1971)].
14. L. L. Johnson, E. W. Merrow, W. S. Baer, A. J. Alexander, *Alternative Institutional Arrangements for Developing and Commercializing Breeder Reactor Technology* (The Rand Corporation, R-2069-NSF, Santa Monica, Calif., 1976).
15. J. M. Utterbach, *Science* **183**, 620 (1974); E. Mansfield, *The Economics of Technological Change* (Norton, New York, 1968); *Industrial Research and Technological Innovation: An Economic Analysis* (Norton, New York, 1968); R. R. Nelson, M. Peck, E. Kalachek, *Technology, Economic Growth, and Public Policy* (Brookings Institution, Washington, D.C., 1967).
16. L. C. Thurow, "The relationship between defense-related and civilian-oriented R & D priorities," a study prepared for the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee and the Library of Congress, Washington, D.C., 23 April 1976.
17. Supported by the Experimental Technology Incentives Program (contract 4-35959), U.S. Department of Commerce. C. Johnston Conover, Cheryl Cook, Patricia Fleischauer, Bruce Goeller, William Hederman, Richard Nelson, Richard Rettig, and John Wirt undertook some of the individual case studies and made other contributions to this study. We thank J. Hosek, J. Lewis, J. Logsdon, and E. Rolph for helpful comments on earlier drafts. Portions of this article were drawn from Rand reports R-1925-DOC and R-1926-DOC.

NEWS AND COMMENT

Charged Debate Erupts over Russian Beam Weapon

The affair of the charged particle beam, the death-ray weapon with which the Soviets will allegedly soon be able to neutralize an American strategic missile attack, has been the sensation of the week in Washington. Congressmen have received secret briefings, the CIA has been moved to issue one of its infrequent statements, and there has even been a presidential assurance that the nation is not in jeopardy.

The immediate cause of the stir is a 7000-word article in the 2 May issue of *Aviation Week* detailing the case for believing that the Soviet Union has made a breakthrough in the field. An accompanying editorial by editor Robert Holtz states that the United States is in danger of "a crippling technological surprise that could render its entire strategic missile force ineffective."

The weaponeers' hope is to generate a beam of charged particles, similar to those used in accelerators but much more powerful, and to use it to inactivate incoming missiles. According to *Aviation Week*, Soviet scientists have learned how to harness nuclear explosions to drive such a beam. Unnamed officials quoted in the article suggest that the weapon "could be in operational form by 1980" and that the Russians are "years ahead in most areas" of particle beam technology.

Aviation Week is a copious source of military and intelligence information, so much so that it has earned the sobriquet of *Aviation Leak*. Its statements on the charged particle beam could not be ignored, and the Administration was soon set abuzz with denials that the Soviets had achieved any breakthrough in developing the weapon. Briefed by his science adviser and others, President Carter said that "We do not see any likelihood at all, based on our constant monitoring of the Soviet Union as best we can, that they have any prospective breakthrough in the new weapons systems that would endanger the security of our country."

The CIA announced it did "not believe the Soviet Union has achieved a breakthrough which could lead to a charged particle beam weapon capable of neutralizing ballistic missiles." The agency also denied the assertion in *Aviation Week* that CIA analysts had failed to pass on information about the beam weapon to higher government officials.

Far from being chastened by these high-level denials, *Aviation Week* responded that the President was being "screened from vital technical developments" by the bureaucracy of the CIA and the Defense Intelligence Agency. Carter had been incompletely briefed,

editor Hotz announced; his advice: "Dig deeper, Jimmy."

The statements by *Aviation Week* and the Administration represent the two sides of a debate that has been simmering for several years within the intelligence community and which is now being played out in public. The side that lost out in the secret debate was the first to go public, and the 2 May article in *Aviation Week* is essentially the statement of its case.

The chief proponent of the view that the Soviets have made a breakthrough with particle beam technology is Major General George J. Keegan, former head of Air Force Intelligence. Keegan told *Science* that the *Aviation Week* article is "frighteningly accurate." But according to a prominent scientist who advises the government on military affairs, the article presents a distorted view of the intelligence information available.

Supporters of Keegan's thesis within the intelligence community seem to include, and may be confined to, his fellow analysts in Air Force Intelligence. The CIA certainly disagrees, as does the Defense Intelligence Agency, which might be expected to share Keegan's conservative view of Soviet developments. Lieutenant General Daniel O. Graham, former director of DIA, told *Science* that "one worst case analysis may be right, but something that depends on a whole group of them never is." A group of scientists who were convened to review Keegan's thesis for DIA found it didn't hold up, Graham says.

The House Armed Services Committee on 12 May received a closed briefing on the particle beam from Jack Vorona, DIA deputy director for science and technology. Vorona's presentation apparently indicated that the Soviet threat had been "grossly exaggerated."

As far as scientific support goes, Keegan has repeatedly criticized the scientists who disagree with him, such as those who advise the CIA, arguing that their allegiance to conventional wisdom has blinded them to the unorthodoxy of the Soviet approach. Keegan says he went to "young geniuses under 29" who, by making "several major pioneering breakthroughs," helped to demonstrate the feasibility of the particle beam weapon. Keegan declines to identify the young geniuses, but several sources have indicated that the Foreign Technology Division, a group of scientists and intelligence analysts located at the Wright-Patterson Air Force Base in Dayton, Ohio, is the principal source of Keegan's technical advice.

Keegan first began to speak out about the Soviet particle beam threat after he retired from the Air Force in January this year. In a briefing given in March to the American Security Council he warned that well before 1980 the Soviets "will perceive that they have technically and scientifically solved the problem of the ballistic missile threat." This advantage is being gained, Keegan said later, because Russian scientists are successfully developing a proton beam as an antiballistic missile device, whereas the American effort to weaponize a charged particle beam was abandoned because it was staked on electrons (*Science*, 22 April).

Use of a particle beam as a ground-based ABM device raises severe technical problems such as keeping the beam stable, getting it to propagate through the atmosphere, and maintaining steady aim on a target despite the fluctuations in the earth's magnetic field which might tug the beam about. Advantages would be that the beam could perhaps deliver more energy than would a laser on an incoming missile during the few seconds it was within range. Traveling at close to the speed of light, the beam would also reach its target much sooner than would a conventional missile interceptor.

The trouble with this proposal, according to senior government science advisers, is that even if a particle beam were feasible, it would suffer from the same systems disadvantages as conventional ABM systems, such as being enormously costly and requiring large and highly vulnerable radars.

Should a particle beam weapon be developed, it might be more usefully placed aboard a satellite; fired at missiles shortly after launch, the beam's target would be a large rocket instead of a cloud of MIRV's and decoys. Yet the satellites would be visible and vulnerable if placed in high orbit, and have a significant chance of being in the wrong place if stationed in low orbit. In either case, a simple defense against particle beam attack is to "wiggle" the earth's magnetic field with a nuclear explosion.

The Keegan thesis is presented in detail in the *Aviation Week* article of 2 May. Written by military editor Clarence A. Robinson, the article does not cite Keegan as a source. Essentially it lays out the intelligence and technical data that form the basis of Keegan's case, and describes from Keegan's vantage point the bureaucratic battles by which he tried to make his interpretation prevail.

Keegan's case is founded on his interpretation of Soviet activities at two unusual research facilities, one of them about 35 miles south of Semipalatinsk, the other at Azgir in Kazakhstan near the Caspian Sea.

Reconnaissance satellites, Robinson reports, have identified the following activities at the Semipalatinsk site. There is a large main building with reinforced concrete walls 10 feet thick. Satellite-monitored activities indicate that in an underground granite cavern nearby, two hollow spheres, 18 meters in diameter, have been constructed from thick steel segments. Pipes have been seen leading from the chamber. On several occasions satellites have monitored large amounts of hydrogen gas released from the site.

Aviation Week offers this explanation of what is happening at the site. In the underground granite chamber is a "fission explosive generator." (An explosive generator produces pulses of high power by driving metal through a magnetic field; a fission explosive generator would presumably use a train of nuclear fission explosions to drive the metal.)

The underground steel spheres, according to the *Aviation Week* account, are needed "to capture and store energy from nuclear-driven explosives or pulse-power generators." From the generators in the granite chamber, power is carried through cables to nearby transformers, where it is stepped up; thence to "giant capacitors" inside the large building on the surface. Power from the capacitors is fed into a "collective accelerator" and an electron injector gun, to produce a beam of protons. To simulate operation in space, the beam can be bent by magnets into evacuated underground tubes about a kilometer in length.

The copious hydrogen releases detected by satellite are interpreted as the result of the gas escaping from cryogenic cooling of the underground tubes. The seven occasions since November 1975 on which the gas has been detected are believed each to be tests of the beam weapon.

The site at Azgir, in the Keegan view, is believed to house a "far more powerful fusion-pulsed magnetohydrodynamic generator," also in a subterranean cavern. A test of some kind was monitored by satellite late last year.

The Keegan team's hypothesis has been reviewed several times by the Nuclear Intelligence Board of the CIA, the *Aviation Week* article reports, but the board has so far "rejected their conclusion that beam weapon development is evident," and does not agree that either the Semipalatinsk or the Azgir site is being used for beam weapon work. The hypothesis was also considered by the Munitions-Armaments Panel of the Air Force Scientific Advisory Committee.

The panel, it was reported, "rejected virtually all of the Air Force's hypotheses" during a 3-day review and outlined seven theoretical roadblocks that would prevent development of a particle beam weapon. Keegan's team then set about assembling evidence that the Russians have overcome each of these seven roadblocks and in fact are "years ahead" of the United States in most of them.

The article reflects Keegan's view that his ideas have not received fair consideration from the various scientific reviewers. Most of the physicists who would not accept his data are "older members of the scientific community," who were involved in Project Seesaw, the unsuccessful attempt to develop an electron beam, and whom Keegan accuses of believing the Russians could not succeed where Americans had failed.

As to how the defense would detect incoming missiles and aim the beam at precise targets, *Aviation Week* suggests that precision aim is unnecessary. All that is needed is for the beam to saturate the broad areas or "windows" through which the warheads must pass. In the Keegan view, such windows can be detected by the Soviet radars which have already been deployed in violation of the SALT agreement. The typical energy levels that would be required for use with a beam weapon are "10^{12} joules per pulse, with the energy of a particle of the beam from 1 to 100 giga electron volts," the article reports.

Keegan's hypothesis rests on a mix of technical and intelligence information which is too esoteric for easy evaluation. Keegan declines to identify his scientific supporters, and *Science* has been unable to do so independently. Sources have indicated that the Foreign Technology Division at Wright-Patterson Air Force Base is the chief source of Keegan's technical advice, but chief scientist Anthony Cacioppa declines to make any comment. Another rumored adviser, William Drummond of the University of Texas, says he knows Keegan and has advised the government in the past, but that "We are not the advisers of whom he speaks—where he gets his information is way beyond my ken." Drummond and M. L. Sloan, a young physicist at Austin Research Associates, are developing an accelerator capable of generating intense beams under a contract from the Ballistic Missile Defense Agency.

Skeptics of the Keegan hypothesis are easier to find. A physicist who is prominent among the goverment's scientific advisers describes as "absurd" the suggestion the Russians would use nuclear explosions to power a beam. "That is nonsense because the 10 megajoules you would need to destroy a target could just as well be obtained from a conventional high explosive," he says. "I believe there is really nothing to worry about in this case, and that the information provided there [in *Aviation Week*] is a hodge-podge of things which, since you don't know what they are for, can be put together to mean almost anything."

A similarly definite dismissal was delivered by Secretary of Defense Harold Brown at a recent press conference. To turn particle beams into a practical weapon, let alone an operational system, Brown said, "requires that each of a number of theoretically conceivable but practically very difficult steps be carried out. From what we can see of the evidence, and I have seen all the evidence there is, a number of those remain far from achievement both by us and by the Soviets. And therefore, I don't think that there is such a weapons system in prospect in the foreseeable future."

In a further effort to shoot down the *Aviation Week* article, the Defense Department held a 16 May briefing about Soviet and U.S. progress with particle beam weapons. A Pentagon scientist who asked not to be named remarked on the absence of certain "key pieces of information" which would be expected if the Russians had made substantial progress. He declined to identify them, but presumably the testing of a nuclear-powered beam would leave more traces than just a few puffs of hydrogen. Soviet progress with beam weapon-type accelerators is "about equivalent" to that of the United States, leading in some areas and lagging in others, the official said. The United States spends about $7.5 million a year on beam weapons, but a prototype is many years away.

Reaction in Congress seems likely at present to follow similar lines. A staff member of the research and development subcommittee of the Senate Armed Services Committee said the beam threat had been exaggerated and was not likely to become an issue.

The evidence presented in *Aviation Week* establishes at most the possibility that the Russians are experimenting with development of a particle beam weapon. It is presumably the job of intelligence analysts to fit together strands of disparate evidence and make exactly the kind of creative deduction that Keegan has done with the particle beam. But most such hypotheses presumably turn out to be wrong. Keegan's arguments have evidently proved less than compelling to a majority of the intelligence community, but he or his team believe so strongly in the rightness of their case that they have taken it to the public, despite the risk that open discussion of intelligence matters may jeopardize sources and reveal the extent of American knowledge about Soviet activities. The evidence of the *Aviation Week* article seems a tenuous basis for so decided a step.—NICHOLAS WADE

"Soft Technology" Energy Debate: *Limits to Growth* Revisited?

One of the strongest undercurrents of energy policy in recent months has flowed from a remarkable critique put forward by Amory Lovins, a physicist turned environmental advocate for Friends of the Earth. The critique encompasses technical, economic, social, and philosophical aspects of energy policy and appears likely to have a lasting impact on the rhetoric, if not the substance, of the energy debate. It has provoked rivulets of reaction that include congressional inquiries, official studies by the Energy Research and Development Administration (ERDA), detailed and often impassioned rebuttals by many of the elite of the energy establishment, and even imitation by President Carter's speechwriters.

The sequence of events is strongly reminiscent of those following publication of the 1972 Club of Rome report, *Limits to Growth*, which was also vigorously debated and heatedly condemned. The similarity may, in fact, go further,