# THE SSC'S END: WHAT HAPPENED? AND WHAT NOW?

The decision by the US government to terminate construction of the Superconducting Super Collider at 20% completion is a tragedy. Much has been, and will continue to be, written about the background of this action. My purpose here is to discuss this history as it bears on the relation between the US government and the scientific and academic communities.

The design parameters of the SSC were first developed at a Cornell meeting in April 1983. The then science adviser to President Reagan instructed a subcommittee of the Department of Energy's High Energy Physics Advisory Panel, convened in July 1983, to be "bold and greedy," and the President approved the SSC in 1987 with the phrase "throw deep." Both houses of Congress in 1989, 1990 and 1991 provided appropriations for construction of the project, which has received more peer review and public exposure than any other basic scientific enterprise. Committee after committee designated the SSC as the highest-priority project in high-energy physics, and both succeeding Presidents supported the SSC.

The conceptual design of the SSC was produced by the Central Design Group, headed by Maury Tigner of Cornell, under contract between the Department of Energy and the Universities Research Association. When the CDG concluded its work, DOE was unwilling to extend URA's responsibility from design to construction and instead threw construction responsibility open to competitive bidding. Several industrial companies considered bidding, but URA was the only corporation to finally respond. As part of its proposal URA had to select the senior staff for the laboratory in a crash process and was compelled to "team" with two industrial firms to broaden support in Congress.

Twenty-five states expressed interest in the project by submitting site proposals. Yet after DOE selected the site in 1988 following a preliminary screening by the National Academy of Sciences, national support gradually eroded. Neither the scientific community nor the Federal government was able to erase the image that the SSC was "Texas pork." Yet the collider was a truly national and even international undertaking, with 75% of its budget allocated to purchases outside the laboratory.

Past accelerators managed directly under government contract with US universities or consortiums of universities (with the exception of Isabelle, which was overtaken by other advances in high-energy physics) have generally been constructed on budget and on schedule and have performed in excess of expectations. The average overrun of all such postwar projects has been less than 10%. This record contrasts sharply with the experience in NASA, where the average construction overrun has been a factor of 3; postwar reactor enterprises, with overruns averaging a factor of 10; and high-technology defense undertakings. Yet government officials continued to ask, Can academic "eggheads" build a $10 billion project, given their successful experience up to "only" $1 billion, or should the job be given to industry, with experience extending into the tens of billions of dollars but with an established record of overruns?

Major scientific laboratories operated by universities for the government after World War II were not simply contractors but *partners* with government, with both parties sharing a common interest in scientific achievement. But now this postwar partnership is eroding. It is sharply criticized in Congress as providing insufficient accountability. Attitudes are growing that scientific projects should be "acquired" through competitive procurement rather than supported by the government in response to scientific initiatives.

Under the Bush Administration, Secretary of Energy Admiral James Watkins, following the tradition of the nuclear Navy, wanted *his* people to be directly responsible for the SSC. He established a local DOE office at the SSC whose chief was given the dual titles of project director and associate director of energy research, reporting both to the DOE director of energy research and to Watkins. Few if any of the DOE overseers had relevant knowledge or experience in accelerators or science, yet they exercised veto power over virtually all technical decisions. Watkins conditioned his approval of the project manager within the SSC Laboratory on the creation of a position of general manager, to be filled by his designee. Traditionally DOE's role has been policy setting, oversight and contract management, while the SSC Laboratory should have had line responsibility for constructing the SSC and creating an environment in which scientific research could flourish. But these roles were never confirmed nor denied throughout the history of the SSC.

The sheer volume of oversight, reviews, appraisals, audits and other investigations of the SSC was unprecedented. Counting personnel from the DOE site office, the DOE inspector general, staff from the General Accounting Office of Congress, URA's overseers and Congressman John Dingell's subcommittee staff, well over 100 people involved in such activities visited or populated the SSC Laboratory, which had to dedicate equivalent manpower in response. Short deadlines and review meetings preempted the time of senior laboratory personnel. Most insidiously, much of the technical personnel of the laboratory was preoccupied with responding to these pressures.

The sheer size of the undertaking, the micromanagement by DOE, and the intensity and frequency of external oversight all led to a bureaucratic internal culture at the laboratory. In the name of cost control, technically needed changes and design trade-offs were discouraged. Decisions on technical alternatives were distorted by "political acceptability" and were at times made late or not at all. Control of contingency funds remained in the hands of DOE. Key scientific and technical people were generally placed low in the decision chain.

All these conditions were frustrating to the capable technical and scientific people at the laboratory and made recruiting from the academic community and other national laboratories difficult. It proved impossible to retain more than a very few of the key individuals among the CDG designers of the machine. Experienced accelerator design talent at the SSC Laboratory was scarce when measured by the standards of other successful laboratories. Notwithstanding the ranking of "highest priority" given to the SSC in successive peer reviews, the members of the high-energy physics community did not "vote with their feet" in joining the SSC. While nearly half of the US high-energy physics experimentalists joined the collaborations proposing SSC detectors, accelerator and particle physicists largely remained at their home institutions. Therefore most of the technical talent of the SSC Laboratory was recruited from industry. The SSC director faced the problem of merging the cultures of universities and national laboratories with that of the military–industrial complex. The laboratory and its director faced opposing pressures and criticism. DOE emphasized formal process and accountability, largely disregarding technical substance, while the scientific community demanded adherence to practices proven successful for smaller undertakings.

Yet in the face of all this turbulence, timely but inefficient progress was made. Bids received on civil construction were generally low, partially because of adverse economic conditions. Fifteen miles of tunnel were completed. Cooperation on the superconducting magnets between the SSC and Fermilab, Brookhaven National Laboratory and Lawrence Berkeley Laboratory enabled the successful transfer of superconducting magnet technology to industrial contractors. In turn those contractors built superconducting magnets at Fermilab meeting all specifications, which were then united ahead of schedule in the string test at the SSC Laboratory that demonstrated the viability of the magnet design. Paradoxically, this success was turned into defeat by government criticism. DOE's inspector general and Representative Dingell criticized the interlaboratory agreements as too informal and not well enough documented.

Much Congressional displeasure focused on cost increases. In 1989 DOE gave a $5.9 billion (in then-year dollars) project cost estimate to Congress. The first site-specific total project cost estimate, submitted by the SSC Laboratory in mid-1990, was $7.8 billion. Administrative overhead proved to be larger than estimated: Environment, safety and health people had to be added. Items such as a library and an in-house physics contingent, which would be necessary to create a viable laboratory, had not been included in the original estimate. More detailed calculation of expected beam losses in a necessarily imperfect collider ring led to a decision to increase the dipole

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magnet aperture by 25% and to double the energy of the High Energy Booster. A proposal to cancel these cost increases by reducing the SSC energy and shrinking the collider radius accordingly was rejected by HEPAP, URA and laboratory management, and Admiral Watkins approved a total project cost of $8.25 billion late in 1990. Would the laboratory still be alive today if the SSC energy had been reduced to contain the cost? Cost estimates since that time have been quite stable, except for added costs associated with a construction schedule stretch-out; of course risks of further cost changes remained.

When first announcing President Reagan's support for the SSC, Secretary of Energy John Herrington touted the accelerator as an example of American competitiveness. The theme changed to "foreign partnership" during the Bush Administration, but Congress remained divided on whether foreign contributions to building the SSC were good (in that they would save taxpayer dollars) or bad (in that they would export American jobs). Solicitation of foreign contributions was successful only with Russia and China (which agreed to provide components at less than one-half of American costs), but Japan continued to postpone its decision. India offered a contribution, but that proposal received no successful follow-up. DOE insisted that foreign contacts were its prerogative and its alone, frequently resulting in unproductive foreign missions.

Above all the SSC became caught in the rising budget debate within the United States. Liberal elements in Congress resented the Texas delegation's opposing social programs and funding while insisting on billions for the SSC. The Clinton Administration adopted a policy of matching tax increases with budget cuts. The elections of numerous new representatives reflected a mandate to reduce government spending. All this gave rise to anti-SSC votes in the House of Representatives first in 1992 and then in 1993. The latter vote ultimately prevailed in the Senate, killing the laboratory.

What actions could have prevented this tragic outcome? Would a more resolute determination by URA and the SSC Laboratory's director to resist DOE's encroachment on technical and scientific decisions have reduced the problems or produced an earlier death? Conversely, should there have been even more compromise with the DOE bureaucracy? Could the SSC management have prevented the excessive growth in administrative burdens? Could the internal SSC project management control systems have been put in place sooner and been more capable? Could the SSC director have made firmer and more timely decisions? Could technical recruiting have been more intensive and effective? Would foreign contributions have become more substantial if DOE had conducted foreign contacts more sensitively? These questions will remain largely unanswered.

Irrespective of these issues, the SSC fell victim to larger national forces: *With changes in national priorities, the SSC became too expensive a project to retain support from a Congress consumed with finding ways to reduce government spending.* Under these circumstances no human laboratory director or any form of management could have succeeded.

The SSC history does not project an image of US consistency in the support of science or of furthering true international partnership. How can the US be a reliable partner in multiyear international scientific ventures when Congress appropriates funds annually? We need to begin urgent deliberation about how the US can assume more formal and binding multiyear obligations.

This recital is not a happy one. The death of the SSC may be symptomatic of the fact that any pattern of exponential growth must stop eventually. The mechanism to achieve such a halt will always be painful, whether it arrests the growth of population, of computer capacity or of the energy of accelerators. Perhaps international collaboration can reestablish the now interrupted pattern, and all possible efforts should occur to make this a reality. But above all, it must be recognized that science needs government, and government needs science, and thus restoration of the science–government partnership is essential.

Wolfgang K. H. Panofsky
*Stanford Linear Accelerator Center*
*1/94* *Stanford, California*

With the termination of the Superconducting Super Collider, the physics community should reflect on the failure of the last two major American accelerator projects. From the perspective of a deeply involved supporter of Isabelle and the SSC, both failures can be traced to a common cause. The American high-energy physics community has not accepted the post-Vietnam-era prerequisites for successful major accelerator construction. This refusal, more evident with the SSC than with Isabelle, has led to the tragedy of hundreds of shattered lives at the SSC Laboratory.

It is convenient to blame Congress or the Federal bureaucracy, but as physicists we know that solutions to real problems must satisfy boundary conditions. Congress only serves as a jury, and physicists are not exempt from the bureaucratic procedures that are now part of all large publicly funded projects. Congress will support large basic research projects even when budgets are tight, but it is unrealistic to expect public funding for a multibillion-dollar project widely seen as "plagued by cost overruns and mismanagement."[1] The success of the SSC's resolute Congressional opposition should not have been surprising after publication of a widely read article[2] in which executive branch and Congressional oversight was dismissed as "the revenge of the C students." This public derogation of the SSC's benefactors, no matter how deeply felt, clearly contributed to the SSC's demise.

Lest we once again delude ourselves about causes, three well-documented facts corroborate the view that the SSC project was badly managed and wasteful. First, even members of Congress who may not have been exceptional students understand that any complex, multibillion-dollar construction project requires a cost control system. However, the SSC Laboratory never implemented a system that could "accurately measure project status and develop meaningful reports."[3] Second after more than four years and the expenditure of over $500 million by the SSC magnet division,[4] the "first prototype magnet" of the type to be installed in the SSC collider tunnel had not been produced.[3] Finally, even C students of project management could determine—despite claims to the contrary—that the project was not "on budget." With changes approved through July 1993, more than three-quarters of the project's contingency had been allocated, but less than 15% of the project had been completed.[4,5] When known increases in the cost of collider dipole magnets[3] are properly included and the planned Clinton Administration delay is factored in, the projected SSC costs at completion exceed $15 billion.

The SSC did not fail because of lack of motivation or effort. Good intentions, hard work and physics expertise are not enough; success in such an ambitious undertaking demands more. Dealing with Federal sponsors in a manner they find unacceptable and refusing to comply with disagreeable requirements for publicly funded projects is a certain prescription for failure. Success requires much greater attention to the imperatives of large project management. Others learned these lessons long ago without undergoing such painful experiences as Isabelle and the SSC. The future of American high-energy physics depends on the ability of this community to learn and accept the necessity for project management organization and discipline in large accelerator construction projects.

## References


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3. Report of the DOE Review Committee on the Baseline Validation of the Superconducting Super Collider, US Dept. of Energy, Office of Field Management (August 1993).
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DOUG PEWITT
Lancaster, Texas

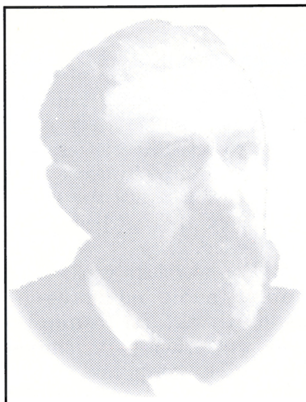
*10/93*

Now that the SSC has been terminated by action of the House of Representatives, it is clear that elementary-particle physics in this country has suffered a major, perhaps devastating setback. Those who have argued in the pages of this magazine and elsewhere so ardently against this scientific enterprise now have the opportunity to demonstrate the ways in which US science is better off without the SSC. In reckoning the impact of the SSC termination, the dedicated effort of thousands of scientists, engineers and students over the past decade must be included as part of the loss. Less tangible effects on the future of particle physics in the US may turn out to be even more regrettable.

Considering the strident nature of much of the commentary against the SSC, it seems to me that those people who have worked so visibly for its termination also have a moral obligation not to ignore the further evolution of support for science and in particular the various branches of physics. They should be able to present evidence that US science is now healthier. I certainly hope the case the SSC antagonists can offer will match the visible damage.


DAVID R. NYGREN
Lawrence Berkeley Laboratory
Berkeley, California

*11/93*



Last week our government decided to scuttle our most visible scientific project, the Superconducting Super Collider. Sadly, its termination portends the premature death of a field of fundamental research in which America has led the world for a good part of this century. The SSC's size and international prestige have made its demise a symbol for the future of US science. The rest of the world, especially our competitors, will with good reason conclude that the United States is relinquishing its leadership role at the scientific frontier. In a society so dependent on being a step ahead in technology, on the scientific education of its work force and on its will to compete, this seems to be a recipe for disaster. At a time of difficult fiscal realities, our country cannot afford to lose sight of the long view, yet we seem to be intent on mortgaging the future for short-term gains.

We must examine the root causes of this turnaround. The case for fundamental research as a *necessary* element of any thriving technological society has not been made convincingly enough to our fellow citizens. The reality before us is that, increasingly, governmental support of science is predicated on demonstrating its immediate relevancy to society. The SSC was the first big victim of this attitude; I fear it will not be the last. This trend is also reflected in recent discussions in Washington, aimed at redefining the "mission" of the National Science Foundation away from its traditional role of funding basic research, to that of facilitator of "technology transfer." It is no coincidence that this attitude has emerged with the end of the cold war, which has put in question the support of all basic science. I do not see the SSC's demise as an isolated event, but as the precursor of an alarming trend.

My greater concern is the effect this quicksand of changing priorities is likely to have on the role of universities. Universities have been the traditional keepers and transmitters of knowledge and culture. Universities have fulfilled this role by teaching and imbuing students with these and by sheltering and training scholars and encouraging them to expand knowledge in *all* domains. To give but a few examples, universities pursue and increase not only knowledge of the physical world (biology, chemistry, medicine, physics, . . . ) but also abstract knowledge (mathematics, philosophy, . . . ), knowledge of ourselves as human beings (art, music, history, literature, . . . ) and knowledge of our interactions with one another (economics, linguistics, sociology, . . . ). Much of that knowledge cannot be justified on the grounds of being immediately relevant. Yet I expect universities will increasingly be required by those who fund them to demonstrate the same type of relevancy that is being demanded of science.

Study of the physical world has led to unimaginable advances in standards of living, for example, through the invention of machines (the steam engine, computers, . . . ) and through developments in medicine that have improved both quality of life and longevity.

Other advances of knowledge, in the humanistic realm, show benefits that are much harder to quantify. Some benefit the soul. It was argued long ago that increased knowledge of ourselves was the key to achieving harmony and happiness. As part of this quest for awareness, understanding our role and place in the physical universe around us was deemed necessary.

Advances in fundamental science rarely show immediate "benefits." Two technological wonders, the uses of electricity and the buoyancy of airplanes, are both based on laboratory studies started over 200 years ago, at a time when their technological uses could not have been imagined. For some reason, in the late 20th century we have come to expect immediate results from basic research—in fact, immediate results from anything.

I view the SSC not as an expensive tool for the use of a few physicists but as a giant microscope that would have allowed the *whole human race* a glimpse of nature it has never seen before. It is not easy to evaluate the impact of opening this new window on our physical world. Historical precedents do demonstrate such increases in knowledge to be important in ways seldom imagined at the time of discovery. Of the "uses" of the discoveries the Super Collider would have made, we can only guess, but we do know that it would have told us about the makeup of the universe a few seconds after the Big Bang. In that sense, the Super Collider was part of our quest for our origins, for understanding our universe and our role in it, and ultimately for understanding ourselves.

In Washington this quest was determined to be too onerous for the wealthiest society on the planet! Are we entering a time of regression away from the path that was started in the Renaissance, a path where natural curiosity and exploration in *all* domains were thought to be necessary and important to further the human condition? Does the demise of the SSC have a greater nefarious symbolic meaning: the signal that the US is turning away from this spirit of exploration and quest for the unknown, and beginning to look inward? Such a turn occurred in China in the 15th century. Five hundred and fifty years later, China has not yet recovered.

Universities are likely to be isolated in the present climate of relevancy. Yet it is precisely when universities are at their most vulnerable that they acquire their greatest importance. Universities keep and nurture parts of our heritage and culture that seem to be irrelevant to many; yet what is deemed irrelevant at one time often becomes overwhelmingly important at another. So it is no surprise that universities are under attack by the very same forces that clamor for relevancy. We live in a "throw away" society. Bent on the course for the relevant, this society will end up throwing itself away. I truly believe that the preservation of our universities in their traditional role is essential to the survival of this country.

What can we do to change this course? We must convince our people that universities are a necessary and important part of their well-being and that of their children. There is a widening education gap between those at the intellectual and technological frontier and the bulk of the society. In a democracy, such a gap can have only one result: a progressive alienation between the two, and eventually a revolution against the frontiers and a turn inward. I fear that the SSC decision is an omen of this alienation.

We need to educate beyond the walls of academia.

We must communicate the joys and thrills that come with rising above and conquering intellectual challenges.

We must emphasize that human beings need not feel lost and irrelevant in a technological world, that they can exist and thrive in harmony with its realities.

We must teach appreciation of the difficulties and challenges of producing any technologically advanced "useful" device, be it a car, a refrigerator, an nmr imager or a computer. Successful marketing of any device often depends on simplicity of use, no matter how complicated the internal workings. Few of us can even begin to appreciate the tortuous path by which any such device comes to existence. This complexity lies not only in the actual manufacturing but also, more subtly, in an interdependence between basic and applied science over long periods of time, and in the development and availability of a very sophisticated work force. This message has not been communicated to those who pay us to educate their children. Thus many seem to believe that such complex tasks can be turned off and then back on at will. One cannot simply "mothball" scientific projects, because their most important component is the people who make them work. In a world where scientific and technological progress is fast paced, "mothballing" people condemns them to obsolescence, robbing the country of their talents forever.

Too many of our people are employed below their abilities; we are increasingly subjected to forms of entertainment (sports, television, movies) that only seldom challenge and motivate us. This state of affairs can last only as long as the society can sustain itself. We cannot hope to keep our high standards of living without thinking toward and investing in the future. Our survival as a competitive society depends on the education of our children, on producing ideas, on thinking of and presenting solutions to the problems facing our society and our planet. As keepers of the flame, it is up to us in the universities to rekindle it.

PIERRE RAMOND
*University of Florida*
10/93 *Gainesville, Florida*

In recent months PHYSICS TODAY has printed letters expressing opinions about the Superconducting Super Collider from members of every imaginable interest group except the education community. My opinion as a high school physics teacher is that if we allow attacks against basic science to go unchallenged, the prevailing view of science will contain little to excite the general public and less to draw students to its study.

I use the study of particle physics as a motivating factor in my introductory physics course at Shady Side Academy and as one of the central areas of study in my advanced physics course. That our physics enrollment is growing shows the advantage of using current topics in science even in introductory courses. Students really want to know why scientists believe in the existence of the nucleus, protons, neutrons, quarks and electrons. The answer in nearly every case begins with experiments at particle accelerators. It's going to be hard to tell these students that American scientists will soon have to go to Europe to ask and answer similar questions.

While my students are fascinated by the pure science of particle physics, they were amazed to learn of one of its spinoffs. The spring 1993 issue of the Stanford Linear Accelerator Center *Beam Line* contains an article on the use of medical particle accelerators in the treatment of cancer. In the article John Ford states, "In a society with health-care services comparable to the United States or Western Europe, the average person has a one in eight chance of being treated on a linear accelerator in his or her lifetime." Further, over 100 000 people in the United States alone are cured of cancer with treatments that include the use of particle accelerators, and this number may double in the near future. It seems to me that this outcome alone more than pays for all of the investments to date in particle physics. For those looking for more, the entire spring 1993 issue of *Beam Line* is devoted to the topic of technology transfer.

I have reason to believe that my students are not unique in being interested in particle physics. Recently, I helped to produce a teaching packet called "Particles and Interactions," which was distributed to the physics teachers at 16 000 high schools across the country. It provides hands-on activities and background for an introductory unit on particle physics. Much of this material relates to the SSC. Teacher responses have been impressive. A random sampling of teachers receiving the packets shows that the average teacher receiving a packet has shared it with two to four other teachers, and the number of students reached per packet has averaged over 200 in the first year. Many teacher responses indicated that the use of these materials has increased physics enrollments for next year. I worry that with the halting of the SSC, this increased student interest in physics will abruptly reverse. Why should anybody study physics if the most visible physics project in history has been shut down by those who represent the people of the United States while already 20% complete? The message is very clear: Physics and physicists are not valued in this country! Enter this profession at your peril!

ROBERT J. REILAND
10/93 *Pittsburgh, Pennsylvania*

I am writing to respond to Rustum Roy's letter (July 1993, page 11), in which he presents his viewpoint on what constitutes a fundamental science. It is clear from his letter, however, that his true intent is merely to continue his public diatribe against the Superconducting Super Collider. Roy simply does not understand that basic research by its very nature does not require justification in terms of its practical benefits to society or its impact on other scientific disciplines. Rather, some topics are studied simply to satisfy the insatiable intellectual curiosity that we have developed as humans after millions of years of evolution. The mechanism of electroweak symmetry breaking and the mystery of fermion mass generation may not be sufficiently tantalizing to provoke Roy's intellectual curiosity; then again, perhaps nothing is, outside his own area of research. His claim that "funding the SSC is merely funding a public works project" is an insult to all the open-minded scientists, within and outside particle physics, who have the intellectual capability to appreciate the monumental scientific significance of the SSC, even while arguing over the relative cost.

CHRISTOPHER CARONE
*Harvard University*
7/93 *Cambridge, Massachusetts*

ROY REPLIES: Now that the public expenditure of $38 billion ($13 billion plus interest for 25 years) for the SSC has been rejected by Congress, the debate can turn to how a tiny group of citizens came to feel—fervently, passionately, indeed self-righteously—that the nation's taxpayers—fast-food workers and single mothers and corporate executives—"owed" them that enormous sum. Only one explanation fits: the "monumental scientific significance" (as Christopher Carone puts it) of the SSC for *them*. Carone chose not to use the more usual formulation that the SSC would reveal the "secrets of the universe," "the mind of God" and so on. But I ask him and his colleagues to please consider that 99.9% of the citizenry do not subscribe to their religious convictions. And nobody is stopping anybody from satisfying their "insatiable intellectual curiosity" with their own money or private contributions. His "monumentally significant" science, I note, will not make one whit of difference to those citizens. It will never be used, never be cited, in any research in most of physics, in chemistry, in materials science or in biology. Alvin Weinberg's classic criterion for the importance of any science—its effects on neighboring fields—gives the Higgs boson a zero score.

I regret that the breadth of my intellectual interests does not measure up to Carone's standards. After all, besides materials science I've only written a dozen papers or books each on K–12 science education, peer review, national science policy, technology and religion, and even a bestseller on human sexuality. Lack of curiosity does it every time.

RUSTUM ROY
*Pennsylvania State University*
11/93 *University Park, Pennsylvania*

## Take Physics Teaching Back to the Basics

Recent discussions in PHYSICS TODAY about the status and needs of our profession impel me to comment from the perspective of a half-century spent as a physicist–engineer in industry, academia and national laboratories.

Despite innumerable demonstrated benefits to society, modern technology is encountering increasing hostility from the press, politicians and pulpits. The news media seem kinder to astrologers, mystics, radical environmentalists, rock stars and religious fundamentalists than to scientists and engineers. Public affairs focus increasingly on issues with which very few public officials and too few news reporters are capable of dealing rationally, because they involve science and technology. The general public must have a better understanding of elementary science. To that end, society today should encourage and reward teaching more than research. Super Colliders and space stations can wait for better times; education cannot.

There is no shortage of advanced physicists today, but there is a deplorable dearth of good secondary school science teachers who can motivate students to enjoy and apply science rather than simply entertain or try to impress them with material on the frontiers of research that has little or no relevance to our daily lives. They, not more PhDs who require expensive facilities for investigating arcane phenomena, are what today's physics departments should be producing and society rewarding.

During a decade on the faculty of an engineering school, I saw how teaching suffers when the faculty member must also raise the funds not only to support his research but to pay for his graduate students and maintain his salary. Now that scientific research has lost the prestige and urgency it enjoyed when this country was on a war footing, scientists must work even harder than I had to then to raise funds for research, and their students are the losers.

Moreover, I'm disturbed about some recent trends in methods of teaching physics. I don't think one can learn basic physics at the video display terminal of a personal computer; there, one learns only how to manipulate numbers and be entertained. In my final decades as a research physicist I observed that although younger physicists were far better than I at *computing*, very few had the intuitive "feel" for phenomena that I did; they had an almost religious faith in a computer printout, even when the input data or the program was faulty. The mental concepts one receives working at an Atwood's machine, a telescope, a Foucault pendulum, an optical bench, a reactor console or a Wheatstone bridge are *fundamentally different* from those one receives modeling those same phenomena at a computer terminal. Electronic "black boxes" make possible very precise measurements, but they can't impart the understanding that one gets from using an old-fashioned galvanometer with an Ayrton shunt, nor can they always be trusted to function as advertised. The slide rule is far less precise than a 16-bit computer, but its use reminds the experimenter that he or she is usually dealing with imprecise data.

As for subject matter, today's elementary university physics course should be part of a larger general science curriculum embracing chemistry, geology and biology that is required of the general student body. It should concentrate on explaining the phenomena of everyday experience and impart the understanding needed to deal rationally with the role of technology in today's society. It should emphasize Newtonian mechanics, heat, optics and electromagnetism, then thermodynamics, atomic physics and elementary nuclear physics, because they are central to the evaluation of alternatives for energy production, of the postulated greenhouse and ozone hole effects, and of many other environmental concerns, and to deciding the proper emphasis of a space program. Quanta, quarks, quasars, the wave–particle dualism, high-energy particle physics and Big Bang cosmology are not relevant to any matters of public concern except insofar as they affect the Federal budget, and I doubt that a "theory of everything" will be applicable to anything practical. Those topics are important for only a small minority of the profession.

Finally, why must the physics profession be concerned about the ethnicity and gender of its members? It should be completely blind to color, national origin, sex and political affiliation. "Affirmative action" is discrimination! Intelligence, dedication, integrity, sense of responsibility, creative ability, attitude—those and *only* those are what should matter in a scientist. Often when confronting one of those annoying questionnaires that ask, "Are you a member of a minority?" I reply, "Yes, a minority of one!"

But I do hope that I am *not* a minority of one when it comes to these opinions!

GEORGE C. BALDWIN
8/93 *Santa Fe, New Mexico*

## 'Sustainable Growth' Is Insupportable

In his "Candidate's Statement," a candidate for general councillor of the American Physical Society says that "we need to limit the growth of the physics community in the USA to sustainable levels."[1]

"Sustainability" is a buzzword in today's global society, and I feel that the term is often used with no recognition of its implications. "Sustainable" implies "for a very long time." The size of a steadily growing quantity varies as $e^{kt}$, where $k$ is the fractional change per unit time. For all positive values of $k$, this size approaches infinity when $t$ becomes very large. Thus there is no positive value of $k$ that can be sustained, and so the term "sustainable growth" is an oxymoron. In contrast, $k = 0$ might be sustained, and some values of $k$ in the range $k < 0$ can be sustained.

We need to be more precise in our use of the term "sustainability." If one advocates continued growth of the physics community in the US, one should specify either the recommended value of $k$ or the recommended way in which a desired value of $k$ can be determined. If one advocates "sustainability," one needs to know that this limits $k$ to values less than or equal to zero.

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ALBERT A. BARTLETT
*University of Colorado, Boulder*
7/93