Thoughts of a retiring APS president

The past year's events prompt reflections on the social responsibilities of scientists, 'Star Wars,' APS activities and Andrei Sakharov's return to Moscow from exile in Gorky.

Sidney D. Drell

I view this talk as an occasion for a bit of self-indulgence. It is an opportunity to say a number of things that have been on my mind on a broad range of subjects.

As I review the 40 years since I joined the APS in 1947 as a first-year graduate student, I realize first and foremost what an enormous gig we have been on. We have made breathtaking progress on our voyage of discovery during the second half of the 20th century. We are now dealing with concepts we could hardly imagine 40 years ago. In the same way that we look back on the 17th century and the time of Isaac Newton as a time of wonder at the discovery of the universality of nature's laws, laws that apply to the Solar System as well as to phenomena on Earth, so will the inhabitants of the 21st century and beyond look back to this amazing era. They will see that enormous progress was made toward achieving a unified theory of nature's forces and building blocks. They will see the first bold strokes of a picture—of a theory rooted in data—of how our universe evolved from the Big Bang of some 15 or so billion years ago. They will also find momentous achievements of both basic and applied significance that are remaking the structure of the familiar world—high-temperature superconductivity being just the most recent.

But, just as we have dreamed of profound new understanding and progress, perhaps of a complete theory of everything, we also have created a nightmare with our scientific advances. The nightmare is simply this: Because modern science has given us weapons of such enormous destructive potential—bacteriological as well as nuclear—the dream may end in a holocaust of almost unimaginable proportions and consequences.

Humanity faces no greater challenge than to avoid such a holocaust. Toward the end of World War II the United States Strategic Bombing Survey was established to conduct a study of the effects of our aerial attacks on Germany and Japan. After visiting Hiroshima and Nagasaki, the survey team wrote in June 1946, at the conclusion to its report:

> No more forceful arguments for peace and for the international machinery of peace than the sight of the devastation of Hiroshima and Nagasaki have ever been devised. As the developer and exploiter of this ominous weapon, our nation has a responsibility, which no American should shirk, to lead in establishing and implementing the international guarantees and controls which will prevent its future use.

This remains a challenge to all Americans, but it also has a special significance for the international community of scientists who created the nuclear weapons that pose so grave a danger to our survival. Moreover, this challenge presents an especially difficult dilemma to scientists. We are trained to approach issues such as the danger from nuclear weapons as technical issues. We bring important physical insights to an understanding of the mechanisms of a nuclear explosion, the significance of its power, the reality of radioactive fallout and its deadly human consequences. These facts are crucial and must be understood because they limit the range of practical policies for facing the nuclear danger and seeking to avoid conflict. Laws of nature cannot be coerced or ignored in setting policy goals. But we also face a very profound, fundamental moral issue in dealing with nuclear weapons of mass, indiscriminate destruction. And *this* is a realm to which the scientist brings no special expertise.

Outside of the laboratory the scientist enters a world of policy and politics where shifting and often apparently irrational laws of political and social interactions replace what he is expert at: the disciplined study of fixed, rational and—when fully understood—beautiful laws of nature. In this much more turbulent political realm the scientist may end up disillusioned, even harmed and embittered. Just recall the sagas

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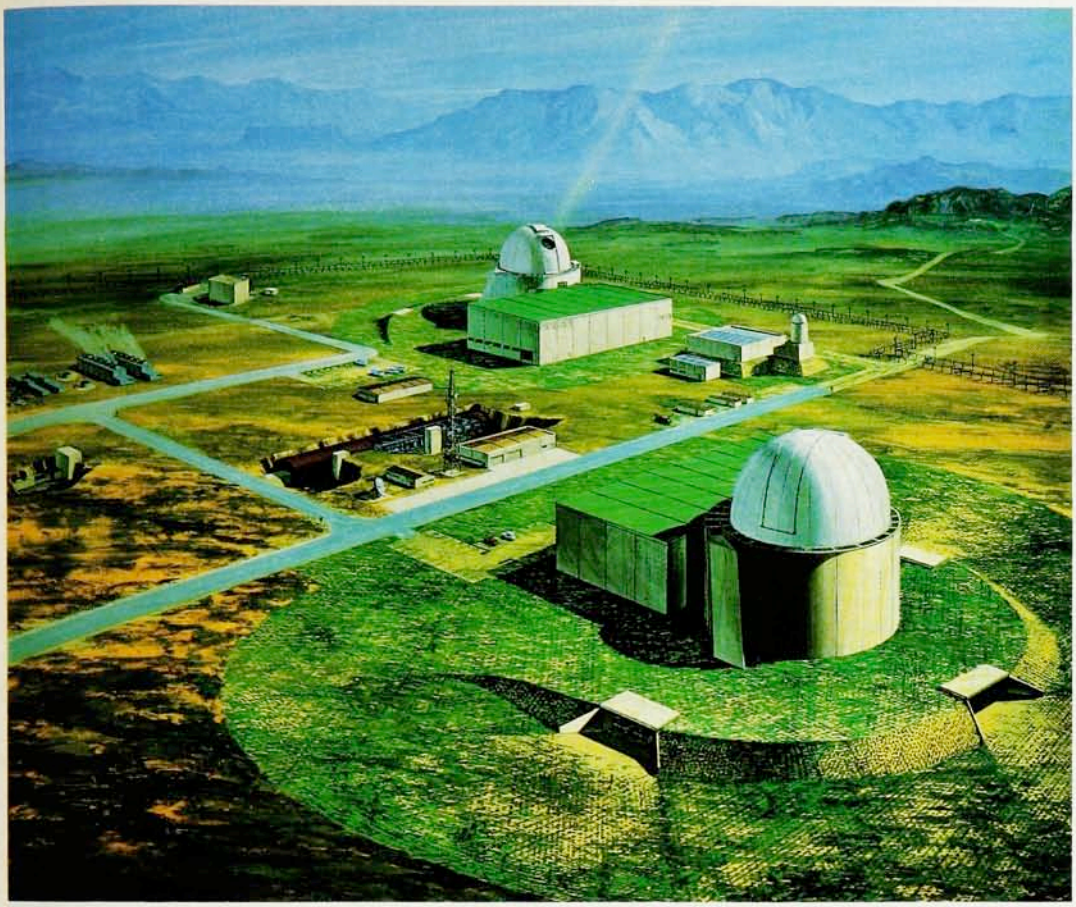


A medium-power free-electron laser proposed for the White Sands Missile Range in New Mexico is shown in this artist's conception. The US Army has asked a team of experts to recommend which of two FEL concepts, induction or rf, should be constructed, and a decision is supposed to be made by June 1988 (PHYSICS TODAY, June, page 17). The White Sands program is designed to explore whether ground-based free-electron lasers, one of the most highly touted directed-energy technologies, can transmit high levels of radiant energy through the atmosphere.

of Robert Oppenheimer and Andrei Sakharov.

It is, of course, not at all new for scientists to be involved in war and weapons of death. Archimedes designed fortifications and instruments of war, including a great catapult, to help thwart the Romans besieging Syracuse in the third century BC. Leonardo da Vinci was renowned as one of the greatest military scientists of his time. Michelangelo was once the engineer in chief of the fortifications of Florence. So there is a very distinguished honor roll of those who have designed and built weapons.

New aspects of an old dilemma

But in our time there is a new element that acutely heightens the scientist's dilemma. Never before have scientists dealt with weapons of absolute destruction, with weapons whose use could mean the end of civilization. Never before have we had so little margin for error. At the same time, the gulf between the responsibilities of our leaders and their understanding of the technological weaponry they command has grown to dangerous proportions. Former British Prime Minister Harold Macmillan lamented this fact in his book *Pointing the Way* (Macmillan, London, 1972):

> In all these affairs prime ministers, ministers of defense and cabinets are under a great handicap. The technicalities and uncertainties of the sophisticated weapons which they have to authorize are out of the range of normal experience. There is today a far greater gap between their own knowledge and the expert advice which they receive than there has ever been in the history of war.

This is a dangerous gap, one we must try to close. Success in closing it will require efforts from both sides: from the scientists as well as from society's political leaders.

I do not view this effort as a moral obligation for every scientist. Each individual, scientist or not, must choose his or her path and goal in society. I do, however, believe that our scientific community as a whole has a special obligation to assist society, through its governments, to understand the implications of the products of our scientific advances and to shape the applications of those products in ways more beneficial than dangerous to the human condition.

It is in this spirit that The American Physical Society undertook the study of the science and technology of directed-energy weapons in 1985 (PHYSICS TODAY, May, page S1).

This subject was thrust into the forefront of public interest by President Reagan's famous "Star Wars" speech of 23 March 1983, in which he called on the scientists "who gave us nuclear weapons to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impo-

Members of the APS study group on directed-energy weapons posed for this photo during the spring meeting of APS in Washington. In the front row, study group cochairman C. Kumar N. Patel of AT&T Bell Labs is flanked by review committee chairman George Pake of Xerox (on his right) and APS President Val Fitch. In the second row, from left, are study group members Andrew Sessler (Lawrence Berkeley Laboratory), Edwin Salpeter (Cornell), Bruce Miller (Sandia National Labs), Thomas Johnson (US Military Academy), Thomas Marshall (Columbia), Richard N. Zare (Stanford), Jeremiah Sullivan (University of Illinois), Charles Hebel (Xerox Corporation), the executive officer of the study, and Petras Avizonis (Air Force Weapons Laboratory).

tent and obsolete." He held out hope of a world freed from the threat of nuclear retaliation by advanced defensive technologies that "could intercept and destroy strategic ballistic missiles before they reached our soil." In response to this call, the APS Council concluded that the society could and should make an important contribution to informed public debate on the desirability and dangers of such weapons systems by independently evaluating the physical basis, the technical feasibility and the related implications of such weapons in an unclassified but thorough technical report.

The issue raised by the President is one of profound importance. What the President is calling for is nothing less than a fundamental change in the basic strategic relationship between the United States and the Soviet Union. Nor is he the first President to raise this issue in search of a safer world to be achieved by applying new technologies to strategic defense.

Every President since Eisenhower upon entering the White House has asked quite properly: Can't we defend ourselves? Can't science and technology provide a shield against the threat of nuclear annihilation? Can't we somehow do better than live as mutual hostages under the condition of mutual deterrence? Upon further analysis and after detailed study of the technical realities, each President until Reagan concluded that the answer was no. This conclusion led to the negotiation during the first Strategic Arms Limitation Talks of the ABM treaty, a treaty of unlimited duration that was ratified in 1972 and that remains in force today.

It was, of course, proper and vital for President Reagan to raise the question of missile defenses again in 1983, in view of the prodigious technical advances that had been made in the more than ten years since the SALT I accords were negotiated. Do these advances now offer us new and better prospects for dealing with the nuclear threat as we look ahead into the future?

I am very proud of The American Physical Society, for we have been able to produce a substantive and superb report on critical technical and scientific issues that have to be addressed in seeking to answer President Reagan's challenge. Under the leadership of Nicolaas Bloembergen and Kumar Patel, a panel of outstanding scientists has striven mightily for the past two years. The panel members have had access to the classified information pertinent to their work and thus were fully informed. Before being issued, the report was given a thorough review by the government to ensure that it was free of classified information. If a society can be judged by the quality and loyalty of those who serve it—on its working committees, as well as its working staff—APS is strong and healthy. I want to express my deep appreciation to all who worked so hard to bring this report forth. It will help those who make good use of it to participate in informed analysis of the pros and cons of the Strategic Defense Initiative.

Star Wars

I personally have been very heavily involved for many years in studying technical and arms control implications of strategic defense. Since being elected to the presidential line of APS more than three years ago I have judged it appropriate to refrain from expressing my views on SDI at society meetings or in society publications, though I have fully presented them elsewhere. Now that I have served my time, however, I feel free on this occasion to express my personal views on what the United States should be doing in strategic defense. These views are based on my best technical judgment and can be summarized in three points:

Support a strong research program that complies with the ABM treaty. A high-quality and balanced research and technology program in strategic defense that is consistent with the ABM treaty is in the security interests of the United States. Compliance with the treaty will impose no harmful technological burden on a properly structured US program for the coming decade.

The gap between today's technology and an effective defensive system is so great that it is now far too early for any program in strategic defense to consider technology demonstrations of types that could interfere with the treaty.

Indeed, our SDI program will be

superior and more likely to achieve its goals of determining what advanced technologies look promising and what systems concepts look practical if its research priorities are not distorted by premature emphasis—or politically motivated requirements—to stage early demonstrations. A considerable body of evidence has shown that early demonstrations of new technologies have two deleterious effects. First, they tend to freeze the technology being demonstrated before it is fully mature, thus guaranteeing less than full capability. Second, they tend to absorb money from the associated R&D program (because of cost overruns), thus eliminating the possibility of better solutions. A funding level of $2–2.5 billion per year is fully adequate to support a strong SDI program.

Do not deploy systems prematurely. A decision to begin premature deployment of a partial strategic defense system would, to put it politely, make no sense. It could not be justified technically and would not serve the security interests of the United States. We must still surmount major technical obstacles before we can consider systems testing, let alone deployment.

Consider, for example, the problem of boost-phase defense. This crucial first layer of a nationwide defense must destroy the enemy's salvo of attacking missiles during their boost phase, within minutes after they are launched and before they can deploy their many thousands of multiple warheads and their potentially hundreds of thousands of decoys.

The only technology available at present to accomplish that critical defensive mission must rely on space-based chemical rockets guided to impact by heat-seeking sensors. These are known as "kinetic-kill vehicles" or "smart rocks." For a boost-phase intercept mission, they must be based in space because there won't be enough time for them to reach their targets if they are launched from the ground.

Such hit-to-kill rockets have been successful in recent demonstrations against single planned targets, which were known to the experimenters in advance. However, the US would have to orbit tens of thousands of them on many hundreds or thousands of satellites to counter just the current Soviet missile threat—and the required numbers would increase very rapidly if the Soviets introduced countermeasures.

With the currently available technology for sensors and guidance the hit-to-kill interceptor rockets will weigh many hundreds of pounds. Thus, deployment of a satellite fleet carrying such weapons would require the United States to launch many millions of pounds into space—tens of millions, in fact. Recall that 10 million pounds is more than 160 shuttle loads.

And once in space, the satellites would be extremely vulnerable to direct attack as they circled the Earth like sitting ducks in a shooting gallery. The existing technology of ground-based interceptors with nuclear warheads—already deployed—would pose a particularly acute threat to such satellites.

In a competition of countermeasures and counter-countermeasures with a ground-based antisatellite threat, this kind of space-based defense would be at a serious disadvantage. To use a popular phrase, it might even be called fatally flawed.

First of all, a ground-based interceptor requires considerably less energy to raise one nuclear warhead weighing several hundred pounds to a given altitude than it would cost the defense to insert into orbit at the same altitude one interceptor weighing many hundreds of pounds.

Second, there is the problem of the absentee ratio. The attacking country need only punch a hole in a small fraction—perhaps no more than 10%—of the defensive constellation that is over its launch sites at the time of its attack. The defense, on the other hand, must equip the entire constellation to counter the ground-based antisatellite threat.

For these two reasons, a technology program would have to succeed in reducing the weight of the individual interceptor rockets from today's designs of many hundreds of pounds to no more than a few tens of pounds before this concept could conceivably be of any practical value. Even then serious issues of systems effectiveness and countermeasures would still remain. In particular, the satellites in space must protect themselves against threats from the entire 4π solid angle around them, and they will be vulnerable for long periods of time.

And as the Soviets replace their present lumbering boosters with modern rockets with faster-burning solid-fuel engines that can lift warheads into space in little more than a minute or two, both the time and the space above the atmosphere available for interception will shrink virtually to zero.

I vigorously oppose the current early deployment push, which seems to be largely politically motivated. The element of urgency is distorting the research effort by driving "proof of feasibility" experiments that are expensive and time consuming. Not only is it technically unjustified; it will almost certainly spell the demise of the ABM treaty.

We have to be realistic in assessing the enormously difficult challenge of achieving not just one individual technological objective—such as a very light, high-acceleration rocket or a very high-powered laser—but rather an effective nationwide defensive system that would be faced with enemy countermeasures designed to defeat it.

This is not a matter of man versus nature, which is the character of a technical problem. It is much more difficult: It is man versus man. The system must remain effective against all efforts to defeat it by a determined opponent.

Enforce and clarify treaty provisions. There is a need to relate the provisions of the ABM treaty to what the treaty calls "other physical principles"—that is to say, new technologies—for strategic defense. The ABM treaty has provided the basis for US–Soviet efforts to achieve stability, to seek reductions in nuclear armaments and to avoid war. Although progress in achieving reductions in nuclear arms since the treaty was ratified has been disappointing, we certainly should continue to enforce it unless technical and political developments make it possible to supersede it by a superior peace-preserving regime. What is needed is an effort to strengthen the treaty in consultation with the Soviet Union by resolving outstanding issues of compliance and by clarifying its application to new technologies in strategic defense.

In particular, we need to relate the ABM treaty and clarify the terms of its application on a case-by-case basis to the new physical principles for strategic defense, including space-based battle stations; directed-energy beams; and sensors utilizing lasers, optics and particle beams for threat detection, tracking and transmittal of information to the battle stations.

Unrestrained testing, including testing in space, of the new technologies as advocated under the Administration's so-called broad interpretation of the ABM treaty is not in the strategic interests of the United States. The treaty, as it was interpreted prior to 1985, contains provisions that were designed liberally to allow the signatory nations to pursue strong research and technology programs in strategic defense, while at the same time preventing preparations for rapid deployment of a nationwide defense following sudden withdrawal of a party from the agreement.

It is in our interests to maintain these restraints on the extensive Soviet program in strategic defense. They too have their SDI program, which includes, like ours, the development of powerful lasers.

With regard to the Soviet effort, I hasten to add that I disagree with claims occasionally made that the Soviet program may soon pose a military threat to us. Particularly in the critical areas of battle management, which rely heavily on computers and software, their technology lags seriously behind ours.

An agreement to abide by the provisions of the ABM treaty as they have been enforced up to now will provide a strong impetus to the ongoing negotiation aimed at deep cuts in the offensive strategic arsenals of the United States and the Soviet Union. Achieving such deep cuts is a stated policy goal of both the United States and the Soviet Union. It is clearly a desirable goal in its own right. But in addition, it will be important to the US strategic defense program. Unless the offensive threat is greatly reduced numerically and limited by appropriate technical constraints as a result of major progress in the US–Soviet political dialogue, I see no prospect of building an effective nationwide defense now or of achieving one in the foreseeable future.

The strategic defense program of the United States in the coming decade must not contribute to the dismantling of our current treaty achievements. While one may justly conclude that SDI played a constructive role in bringing the Soviet Union back to the arms control negotiating table, it should not stand as a barrier to progress.

The scientist's responsibility

Many of you may, and probably do, disagree with my views on SDI. No matter what your views, the APS report on the science and technology of directed-energy weapons will, I believe, provide a very valuable primer for better informing you and all scientists, and it can thus contribute to raising the level of public discussion.

I said before that we scientists bear a special responsibility to assist our society to manage better the technological consequences of our scientific achievements. There is another responsibility that I want to talk about, and that is the responsibility of scientists to speak accurately and responsibly on the technical challenges to society. We are, of course, not only citizens but passionate human beings as well. We accept no restraints on our political involvements and actions. And may we always speak out passionately and with outrage when appropriate on issues of social injustice, prejudice and freedom, as Sakharov has done so courageously.

However, when we speak as scientists on the technical issues themselves it is in our own self-interest to maintain the same high standards that we set in our professional lives. It enhances our credibility individually and, in the long run, the credibility and value of the entire scientific community.

I hope that credibility survives the current debate over Star Wars because this issue has so sharply divided scientists into warring camps and has led to a deep schism between a large segment of the scientific community and our government. The fault for this schism may well be attributable to a failure of institutions in our government.

We are dealing here with an issue of fundamental strategic importance, and one that presents an extraordinarily difficult technical and operational challenge. Yet it burst upon the political agenda based on no prior technical analysis. As our distinguished colleague John Bardeen wrote on 13 September 1985:

> President Reagan prepared his speech with no prior consultation either with technical experts in the Pentagon concerned with research in the area or with his own science adviser, Jay Keyworth. I was a member of the White House Science Council at the time. Although we met only a few days before the speech was given and had a panel looking into some of the technology, we were not consulted.

I am convinced by this incident that effective use is not being made of scientific input into technical defense issues at the highest level. The government has a need here. It cannot dispense with scientists and it must also bear its share of the burden of closing the gap between itself and scientists. Its obligation is to arrange for the best possible scientific analysis and advice before risking major decisions or raising impractical expectations. Furthermore, the scientific advice must be neutral and free of political and doctrinal biases. This is not easy to achieve.

President Eisenhower understood these issues well when he created, in 1957, the position of a full-time science adviser in the White House and also established the President's Science Advisory Committee, which served the President and the nation well for more than a decade before it was disbanded in 1973. He also showed his wisdom when he dismissed the issue of the committee members' political affiliations by saying, according to his first science adviser, James Killian, that he liked scientists for their science and not for their politics.

Since the mid-1970s, after PSAC was abolished, numerous scientific groups and numerous individual scientists all

President Dwight D. Eisenhower made a point of relying on scientists for independent scientific advice, regardless of their politics. In the photograph, which was taken at one of the last meetings of Eisenhower's Science Advisory Committee, the President faces James R. Killian Jr and Isidor I. Rabi. In the back row, from left, are Jerome B. Wiesner, George B. Kistiakowsky, (unidentified), Harvey Brooks, Alvin Weinberg, Glenn Seaborg, (unidentified), Emmanuel Piore and Wolfgang K. H. Panofsky.

have urged the Federal government to reestablish a PSAC-like entity in the executive branch. There is clear need for a preeminent science council with working panels, a degree of continuity and independence of action, functioning to give the President an accurate and informed view of the technical components of his basically political decisions. We have no such effective mechanisms at this time.

The effort to compensate, at least in part, for this need is being made at several universities and research centers. In particular, at Stanford University's Center for International Security and Arms Control, we have a program to train mid-career, established scientists in technical issues of national security. Not only do we need their critical and independent analyses of important arms control and defense issues with a major technical component; we also need to bring new talents and energy—a new generation—to bear on these issues. Ours is just one modest effort to replenish a small and diminishing pool of technically trained independent voices.

APS activities

Let me turn next to issues more directly relating to the activities of The American Physical Society. The platform on which I ran in the vice-presidential election of 1983 spoke of my concerns about our publications, our meetings, our support for physics teaching and our overall role in advancing physics. I have tried to address these concerns since then—I now understand their causes better—and I leave office with these views and recommendations:

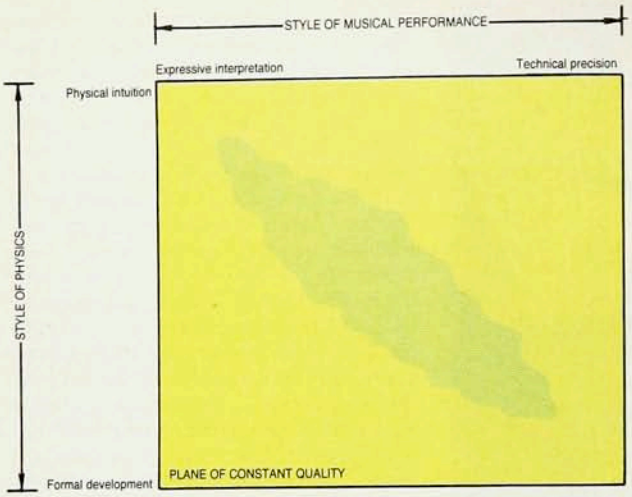
▶ As to publications, while in office I was deeply impressed by the work of editor in chief David Lazarus and his staff. Also while in office I suffered the same frustrations as many of you in waiting for papers to be refereed rapidly and wisely. I have come to Pogo's conclusion: "We have met the enemy and he is us." The society is really trying to make *Physical Review* and *Physical Review Letters* the journals of choice in all fields. We are not satisfied with our record. Without the cooperation of the referees—all of you—we can't do much better.

▶ As to meetings, there are the problems of keeping them all vital, of critical size and of broad intellectual interest. We are striving to retain some of the unity of physics in our meetings. However, if we are to do better, the individual divisions and members will have to behave somewhat more ecumenically even if at the cost of some inconvenience. There are particular difficulties in finding desirable meeting facilities at convenient times. It seems that the personal habits of physicists do not satisfy the profit desires of the convention hotel trade. I am not recommending any changes on that score. But I am especially concerned that we may lose the hallowed and, I think, happy tradition of our spring meeting in Washington, DC. I have appointed a committee under the leadership of Robert Park, the very valuable head of the society's Washington-based Office of Public Affairs, to do its best to save this meeting. Aside from the practical value of coming to Washington for the spring meeting and being able to interact with funding officers, Congressional staff and the like, in this spring season Washington is the most beautiful capital in the world. It is plain nice to be able to meet there.

▶ Having raised the issue of the unity of physics, let me add that APS is continuing efforts to improve the contact between industrial and academic physicists by making the society more relevant to both communities.

▶ At the first council meeting I chaired, in January 1986, I expressed deep concern at the sad state of physics teaching in the public schools. The council voted unanimously to appoint an additional senior staff member whose responsibilities would include strengthening the society's involvement with physics education, working with AAPT and AIP. We were enormously lucky to persuade Kenneth Ford to undertake that responsibility as the APS education officer. He worked very effectively before moving to AIP as H. William Koch's successor in the office of executive director, and his legacy is now in Brian Schwartz's capable hands. I don't know what our long-range effect will be, but the health of our field—and also, I believe, of our country—dictates that we make a serious effort in this area. At present, we have a national crisis owing to the lack of talent and interest in high school physics teaching.

▶ As to advancing physics, the entire leadership of the society has steadily argued for strong funding of basic research, emphasizing the needs of all the major fields and trying to speak for physics in the broad sense of the word. It behooves us not to propagandize for individual subfields and not to descend into destructive arguments between the merits of small and large physics. Let us cease and desist in the use of qualifying adjectives or prefixes before "physics." Physics is beautiful enough



Personal styles in physics and music are closely correlated, all other things being equal, Drell suggests. Among the physicist–pianists with whom he has played violin over the years, those whose style in physics emphasizes intuition tend to be expressive interpreters of classical music, while those whose physics forte is formal development tend to emphasize technical precision in music performance.

as is without being subdivided. The society also has been alert to the potential damage to science and was quick to express opposition when restrictions were proposed on the open exchange of unclassified scientific information and when the Department of Defense threatened to deny research support to scientists opposing its policies.

▶ As a field, physics has failed miserably to attract the great potential of women and minorities to our field. We do significantly worse than all other scientific fields according to *Physics Through the 1990s*, the National Academy study prepared under the direction of William Brinkman. Only 3% of the PhD physicists in the United States are women, and less than 1% are blacks, Puerto Ricans, Mexican–Americans or Native Americans. There is a lot of work to be done.

▶ I applaud the society's Panel on Public Affairs, a committee of very hardworking members that was very capably led during my tenure by Thomas Moss, for investigating a broad range of vital interests and undertaking worthy studies in a serious effort to better understand and help the society have a constructive impact on issues connected with support for science and public policy.

▶ I very much support and appreciate the vigorous efforts of the Committee on International Freedom of Scientists, chaired by Murray Peshkin, in playing watchdog to identify cases in which our physicist colleagues around the world are being restricted from their work on political grounds. When we have judged these grounds to be repugnant or unjustified, we have spoken out and worked in defense of the victims.

▶ Last but far from least, I thank the staff in New York, headed by our Executive Secretary William Havens and Treasurer Harry Lustig, who work so effectively, in more ways than most of us appreciate, to keep the society vital, solvent and responsive to our needs and wishes.

Sakharov

Looking back, I asked myself, what was my most satisfying experience in office? Without a doubt it was sending a telegram to Soviet General Secretary Mikhail Gorbachev on 19 December 1986—it was my last official communication as APS president—expressing my deep appreciation for his action in releasing Sakharov from internal exile in Gorky and permitting him to return to Moscow (PHYSICS TODAY, February, page 121). Early in January 1986, the very first letter I signed as APS president was also addressed to Gorbachev. Noting that 1986 had started auspiciously with concrete new arms control initiatives between the United States and the Soviet Union following the Geneva summit conference of 1985, I expressed hopes for progress during the year in efforts to reduce the threat of a nuclear holocaust.

At the same time I expressed my deep personal concern for the situation of Sakharov and asked if it was too much to hope that during 1986 we might see his return to the normal privileges of Soviet citizens in Moscow. I pointed out that many of the issues that the General Secretary was now emphasizing as policy goals were the same ones that Sakharov had been supporting and speaking out in support of for many years. These include emphasizing the great importance of arms control to lead us away from the risk of nuclear holocaust, of keeping weapons out of space and of ceasing nuclear weapons tests. I said that Sakharov, who together with I. E. Tamm wrote the fundamental paper on the principle of the tokamak, could contribute importantly to further cooperation between our countries in research to harness fusion as a peaceful source of energy.

Finally, I emphasized that in addition to benefiting from Sakharov's voice toward achieving these shared goals, the Soviet Union should honor its greatest theoretical physicist, not isolate him from colleagues and thereby impede his physics research.

So it gave me great pleasure to close my term in office by being able to see this come to pass.

Music and physics style

I recall earlier retiring presidential addresses that have been devoted to reviewing recent progress in the speaker's own field of research. I enjoyed those talks very much. The fact that I have chosen a different path and have devoted so much time in this talk to Star Wars reflects the great importance I attach to this issue and its impact on our security and the fact that I have been working on it a good bit for the past few years. Have no fear that I will now talk about my recent research in pure physics. But in the spirit of self-indulgence permitted to a retiring president and also because I have threatened to do this for a number of years, I want to conclude this talk by presenting some data involving not physics, but physicists themselves.

It has been my privilege through the years to spend many an enjoyable evening playing violin–piano sonatas with good friends who are both superb theoretical physicists and superb pianists. (I am the violin player.) I want to leave you with a correlation function developed from this experience that relates the style in which these friends make music to the way they do their theoretical physics. This correlation is shown in the figure above, which I urge you to notice represents a constant level of quality. The scale is not presented quantitatively for evident reasons, nor do I locate the exact position on this graph of each individual. Let me just say that their names are well known to you: Felix Bloch, Francis Low, Gerard 't Hooft, Walter Thirring and Victor Weisskopf. I thank them for the many, many hours of pleasure we have shared. I put no value judgments on any particular corner of the phase space represented in this graph.

Physics is fun. Music is fun. Each of us has his or her own individual style. In different activities our styles are often correlated. Physicists form a great community, and I want you to know I very much enjoy being a part of it.

Thank you. □