Perspectives On The American Physical Society Directed Energy Report

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PREFACE

The American Physical Society (APS) report on the Science and Technology of Directed Energy Weapons has prompted considerable public comment. In order to provide a brief summary of the report contents and the general conclusions which it has generated, as well as to indicate the range of positive and negative criticism which has resulted, the material contained herein has been assembled. Preceding a number of short extractions from various sources is a one-page description of positions which have been taken on different aspects of the report, including some SDIO perspectives. A listing of the selected material is also provided.

This office fully supports informed, vigorous debate on the utility of, as well as the status and development time-table for, directed energy weapons. It is hoped that the attached information can be used as a starting point for further discussions, both classified and unclassified.

JOHN H. HAMMOND
Director
Directed Energy Office, SDIO

Selected Material
Concerning
Directed Energy Weapons

- Report to the American Physical Society (APS) of the Study Group on "Science and Technology of Directed Energy Weapons" - April 23, 1987.

  Consists of over 400 pages of technical analysis and identification of key technical issues. To be published in "Reviews of Modern Physics." Herein termed the "APS Report." (Not attached, but preprint available from APS, 2000 Florida Avenue, N.W., Washington, D.C. 20009).

- Observations and Conclusions on APS Directed Energy Report - May 22, 1987 (following page).

  Prepared by Directed Energy Office, SDIO.

- Executive Summary and Major Conclusions of APS Report -April 23, 1987 (Tab A).

  Comprises the first 24 pages of APS Report. Included here with title page listing members of the APS Study Group (which authored the Report) and members of the associated APS Review Committee. Reproduced for official government use only.

- APS and SDIO Press Releases - April 23-25, 1987 (Tab B).

  Two APS releases entitled, "Feasibility of Directed Energy Weapons for SDI is Examined" and "APS Statement Urges No Early Commitment to SDI Deployment." One SDIO release commenting on APS Report. One Albuquerque Tribune article by member of APS Study Group entitled "Physicist Confident of SDI Technology."

- Presentations to the House Republican Research Committee, May 19, 1987 (Tab C).

  Statement by Dr. Frederick Seitz, former President of the APS and currently Chairman of the Science Advisory Committee for the SDI. Joint statement by Drs. Lowell Wood and Gregory Canavan of Livermore and Los Alamos National Laboratories, respectively.

- Description of R&D status and Schedule for Selected Directed Energy Options.

  Classified. Not included in this package, but available as a briefing from SDIO Directed Energy Office, phone 693-1568.

OBSERVATIONS AND CONCLUSIONS ON APS DIRECTED ENERGY (DE) REPORT

o TECHNICAL CONTENT

- Body of the report provides valuable unclassified tabulation and quantification of major DE issues for the scientific and engineering community. Useful as basis of technical debate and for attracting technical talent.

- Technical arguments, results and currency questioned by scientists (e.g. Wood, Canavan) on some specific points.

- SDIO encouraged by fact that basically no new issues were identified. Welcomes future debate at appropriately detailed technical level, and intends to use report as a benchmark against which progress is measured.

o EXECUTIVE SUMMARY AND CONCLUSIONS

- Summary states that "even in the best of circumstances, a decade or more of intensive research would be required to provide the technical knowledge needed for an informed decision about the potential effectiveness and survivability of directed energy weapon systems."

- This and other Executive Summary points criticized (e.g. by Seitz) as being unsupported by, inconsistent with, and/or exceeding the scope of the body of the report.

- SDIO disagrees with generalized conclusions that oversimplify and trivialize the process of applying many different technologies to a wide range of BMD applications with varied threats and mission performance requirements. The body of the report provides no analysis or discussion to justify specific timeline conclusions. The APS did not examine this question in any degree of detail.

o APS COUNCIL POSITION

- APS states that "in view of the large gap between current technology and the advanced levels required for an effective missile defense, the SDI program should not be a controlling factor in U.S. security planning and the process of arms control."

- SDIO notes that at least several members of the Study Group were not consulted on the Council's statement, which clearly exceeds scope of study. The statement appears unrelated to the Report or to the Study Group charter.

o DEVELOPMENT OF DIRECTED ENERGY WEAPONS OPTIONS

- SDIO is enthusiastic about providing and discussing detailed development and technology timelines for specific technologies and progressive applications at appropriate classification levels. It will continue to promote and participate in unclassified debate to the maximum extent possible.

Science and Technology of DIRECTED ENERGY WEAPONS

Report of The American Physical Society Study Group

April 1987

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To be published in *Reviews of Modern Physics*

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EXECUTIVE SUMMARY AND MAJOR CONCLUSIONS

The American Physical Society (APS) convened this Study Group to evaluate the status of the science and technology of directed energy weapons (DEW). The evaluation focuses on a variety of lasers and energetic particle beam technologies for their potential applications to the defense against a ballistic missile attack. This action by the APS was motivated by the divergence of views within the scientific community in the wake of President Reagan's speech on March 23, 1983 in which he called on the U.S. scientific community to develop a system that "... could intercept and destroy strategic ballistic missiles before they reach our soil...". Directed energy weapons were expected to play a crucial role in the ballistic missile defense (BMD).

The APS charged the Study Group to produce an unclassified report, which would provide the membership of the Society, other scientists and engineers, as well as a wider interested audience, with basic technological information about DEW. It is hoped that this report, detailing the current state of the art and the future potential of DEW for strategic defense purposes, will serve as a technical reference point for better-informed public discussions on issues relating to the Strategic Defense Initiative.

The study concentrated on the physical basis of high intensity lasers and energetic particle beams as well as beam control and propagation. Further, the issues of target acquisition, discrimination, beam-material interactions, lethality, power sources, and survivability were studied.

The technology of kinetic energy weapons (KEW) is not explicitly reviewed, but the role of space based KEW in support of DEW systems is considered in the report where appropriate. Further, many important issues concerning command, control, communication, and intelligence (C^3I), computing hardware, software creation and reliability for battle management, and overall system complexity have been identified but not discussed in detail.

Other issues, which were recognized but not addressed, include manpower requirements, costs and cost-effectiveness, arms control and strategic stability, and international and domestic policy implications.

DEW technology is considered in BMD applications both for midcourse discrimination between decoys and reentry vehicles, and for kill in the boost phase and the post-boost phase of ICBM's. Such consideration has become serious because of numerous technological advances during the past decade in DEW technologies. Although the achievement of an effective defense of the entire nation may require a substantial boost phase intercept component, other strategic defense scenarios, including discrimination for hard point defense purposes, would place less demanding requirements on DEW systems. The Study Group deemed it important to describe the current state of the art in DEW technology, and to evaluate it with respect to substantial boost phase intercept and midcourse discrimination roles.

> **Although substantial progress has been made in many technologies of DEW over the last two decades, the Study Group finds significant gaps in the scientific and engineering understanding of many issues associated with the development of these technologies. Successful resolution of these issues is critical for the extrapolation to performance levels that would be required in an effective ballistic missile defense system. At present, there is insufficient information to decide whether the required extrapolations can or cannot be achieved. Most crucial elements required for a DEW system need improvements of several orders of magnitude. Because the elements are inter-related, the improvements must be achieved in a mutually consistent manner. We estimate that even in the best of circumstances, a decade or more of intensive research would be required to provide the technical knowledge needed for an informed decision about the potential effectiveness and survivability of directed energy weapon systems. In addition, the important issues of overall system integration and effectiveness depend critically upon information that, to our knowledge, does not yet exist.**

The following observations elaborate on the above finding.

We estimate that all existing candidates for directed energy weapons (DEWs) require two or more orders of magnitude, (powers of 10) improvements in power output and beam quality before they may be seriously considered for application in ballistic missile defense systems. In addition, many supporting technologies such as space power, beam control and delivery, sensing, tracking, and discrimination need similar improvements over current performance levels before DEWs could be considered for use against ballistic missiles.

Directed energy weapon candidates are currently in varied states of development. Among the many possibilities, infrared chemical lasers have been under study for the longest period and several high power laboratory models have been built. However, because of their long wavelengths and other technical features, these lasers are perceived to be less attractive candidates for BMD weapons even though they are closest to the required performance levels in a relative sense. Free electron lasers and excimer lasers are currently perceived as more attractive candidates for BMD missions; but few high power laboratory models have been operated, and the scaling required to reach relevant power levels is estimated to be greater than that for chemical lasers. Nuclear-explosion-pumped X-ray lasers, although the subject of much public discussion, are currently under study at the research level. In our opinion their BMD potential is uncertain.[1] Charged and neutral particle beam devices build on an existing base of accelerator technology but require considerable extrapolations beyond current performance levels.

Supporting technologies are also in varied states of development. In many areas, research is progressing at a rapid pace, for example schemes for rapid steering of optical beams, and active systems for tracking to microradian class or better.[2] Other critical technologies, such as the techniques for interactive discrimination, are being conceived and addressed. The same caution described above for DEWs applies here, namely, proposed supporting technologies need to be systematically studied before their performance at parameter levels appropriate to BMD applications can be realistically evaluated.

Like any defensive system an effective DEW defensive system must be able to handle an evolving and unpredictable missile threat. In addition to retrofit and redesign of the missiles themselves, decoys and other effective penetration aids can be developed by the offense over the long times required to develop and deploy ballistic missile defenses. In contrast to the technical problems faced in developing DEWs capable of boost phase kill for defense systems, the options available to the offense including direct attacks on DEW platforms, may be less difficult and costly to develop and may require fewer orders-of-magnitude performance improvements.

A successful BMD system must survive, but survival of high value space-based assets is problematic. Ground-based assets of DEW systems are also subject to threats. Architectures which address the responsive threat are still in their infancy. As an overall BMD system employing directed energy weapons becomes more complex, the currently unresolved issues of computability, testability, and predictability become increasingly critical.

For directed energy weapons to have an important role as a kill mechanism in a strategic defense system, designed to defend the entire nation against a ballistic missile attack, the following requirements need to be met:

I. **For operations in the boost phase:**
   A. Sufficient power/energy from the directed energy weapons to kill the ballistic missile in the boost phase, or to kill the post boost vehicle during the deployment phase.
   B. Sufficient beam quality, pointing accuracy, and agility (retargetability) to deliver lethal powers or energies to targets within the available engagement time provided by the system.
   C. For lasers, optical systems for transmitting beams from sources to targets.
   D. Accurate detection, location of the booster in its plume, and precision tracking from launch detection until kill is accomplished.
   E. Reliable kill verification.

[1] "X-ray Lasers for Missile Defense", Defense Science and Engineering, November 1986, pp. 17-19.
[2] U. S. Congress, Office of Technology Assessment, *Ballistic Missile Defense Technologies*, OTA-ISC-254 (Washington, D.C.: U. S. Government Printing Office, September 1985).

II. **For operations during the midcourse:**

A. Reliable means of discrimination between reentry vehicles and decoys unless all objects can be destroyed.

B. Accurate detection, tracking of a very large number of objects in the midcourse flight, and kill verification.

C. Rapid retargeting and sufficient delivered power/energy from the DEW to destroy the reentry vehicles.

III. **For terminal phase**

We do not expect DEW to play an important role in the terminal phase of the trajectory of ballistic missiles.

IV. **For space based operation**

A. Nuclear reactors or other means to supply adequate electrical power for housekeeping functions.

B. Adequate burst power for operation of DEW during engagements.

C. Space qualified reliability of all components and subsystems on the platform notwithstanding long periods of dormancy.

V. **For system survivability**

A. DEW must be able to operate in a hostile environment during a conflict.

B. DEW must be integrated in an overall system that includes a survivable command, control, communication, and intelligence (C^3I) system.

We have examined most of these issues in some detail, except for items III. IV.C and V.B. The following major conclusions are based on detailed considerations in the main body of the report indicated by relevant section numbers in parentheses.

1. **We estimate that chemical laser output powers at acceptable beam quality need to be increased by at least two orders of magnitude for HF/DF lasers for use as an effective kill weapon in the boost phase. Similarly for atomic iodine lasers, at least five orders of magnitude improvement is necessary.**

The HF/DF cw chemical lasers have been stated to yield power levels exceeding 200 kilowatt with acceptable beam quality.[3] Based on these data, we estimate that even the least demanding strategic defense applications require power levels to be increased further by at least two orders of magnitude while retaining beam quality. However, the laser geometry which achieved the above demonstration will have scaling problems to higher power levels; thus, the combination of power scaling and adequate beam quality remains an open issue. A chemically pumped atomic iodine laser at 1.3 μm has been developed, although at this point only 5 kW of continuous wave power has been demonstrated. Because of atmospheric absorption, the HF laser ($\lambda = 2.8\mu$m) would have to be deployed on space platforms, while the DF laser ($\lambda = 3.8\mu$m) and the atomic iodine laser ($\lambda = 1.3\mu$m) could also operate on the ground. When based in space, chemical lasers face a special set of problems arising from vibrations and the exhaust of the burnt fuel (Section 3.2).

[3] *IEEE Spectrum*, September 1985 and references cited therein.

2. **We estimate that the pulse energy from excimer lasers for strategic defense applications needs improvement by at least four orders of magnitude over that currently achieved. Many advances are needed to achieve the required repetititve pulsing of these lasers at full scale.**

The pulsed excimer lasers have demonstrated single pulse energies of about 10 kJ in 1 μsec pulses from a single module[4] (Section 3.3). This laser currently uses krypton fluoride (λ = 249 nm); the other principal contender excimer species is xenon chloride (λ = 308 nm). From our estimates, assuming an overall propagation loss factor of four, (relay mirror losses, Rayleigh scattering losses, and atmospheric losses), ground based excimer lasers for strategic defense applications must produce at least 100 MJ of energy in a single pulse or pulse train with a total duration between several and several hundred microseconds (Section 6.3). To kill multiple targets a firing rate of ten per second would be desirable. For thermal kill 1 GW of average power would be required (Section 6.2). The gap of four orders of magnitude might be bridged by first combining lasers into modules at the hundreds of kilowatt level, then combining many modules optically. To produce high optical quality beams from the modules, the output from low optical quality amplifier apertures may be combined using stimulated Raman scattering or other means (Section 3.3). We estimate that the techniques for Raman beam combination must be scaled up by two orders of magnitude or more in combined laser power and efficiency from that which has been demonstrated in the laboratory. The technology for phase locking a large number of modules is not yet demonstrated (Section 5.4).

3. **Free electron lasers suitable for strategic defense applications, operating near 1 μm , require validation of several physical concepts.**

The free electron laser (FEL) is one of the newest laser technologies to be demonstrated. Peak powers of approximately 1MW have been produced at a wavelength of 1 μm; peak powers of approximately 1 GW have been produced at a wavelength of 8 mm, demonstrating high gain and high efficiency at that wavelength.[5] Scaling to short wavelengths at high powers is a more difficult technical problem than simply increasing average power. Obtaining high efficiency, high power free electron laser operation at 1 μm requires experimental verification of physical concepts which thus far are only theoretically developed, e.g., optical guiding and transverse sextupole focusing for the amplifier configuration, and sideband and harmonic control for the oscillator configuration.[6] We estimate that for strategic defense applications, a ground based free electron laser should produce an average power level of at least 1GW at 1 μm wavelength, corresponding to peak powers of 0.1-1.0 TW (Sections 3.4 and 6.3).

4. **Nuclear explosion pumped X-ray lasers require validation of many of the physical concepts before their application to strategic defense can be evaluated.[7]**

A sub-committee of the Study Group reviewed the progress in X-ray lasers. A nuclear-explosion-pumped X-ray laser has been demonstrated. This is a research program where a lot

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[4] See reference 39 of Chapter 3.

[5] T. J. Orzchowski *et al. Phys. Rev. Lett.* **57**, 2172-2174 (1986).

[6] See reference 74 in Chapter 3.

[7] E. Walbridge, "Angle Constraint for Nuclear Pumped X-ray Laser Weapons", *Nature* **310**, 180-182 (1984) and reference cited therein: George Miller (Associate Director, Lawrence Livermore National Laboratory) quoted in "Experts Cast Doubt on X-ray Lasers" *Science* **230**, 647 (1985).

of physics and engineering issues are still being examined. What has not been proven is whether it will be possible to make a militarily useful X-ray laser[7] (Section 3.5). Atmospheric interaction limits the use of nuclear-explosion-pumped X-ray lasers to altitudes greater than about 80 km (Section 5.10). The high energy-to-weight ratio of the nuclear explosives makes it possible for these devices to be considered for "pop-up" deployment (Section 9.3).

5. **We estimate that neutral particle beam (NPB) accelerators operating at the necessary current levels ($\geq$ 100 mA) must be scaled up by two orders of magnitude in voltage and duty cycle with no increase in normalized beam emittance. The required pointing accuracy and retargeting rate remain to be achieved. These devices must be based in space to avoid beam loss via atmospheric interactions.**

Structural kills with NPB devices require an equivalent charge of about 1 coulomb (e.g. 100 mA for 10 seconds) delivered at a few hundred MeV, with a beam divergence of 0.75-1.5 microradian (as discussed and calculated in Sections 4.3 and 6.4). Disruption of electronic function because of radiation dose could occur at significantly lower beam parameters, although this kill mechanism is system dependent, and kill assessment may be more difficult. (Chapter 4)

Existing radio frequency (rf) ion accelerators have achieved particle kinetic energies of several hundred MeV, but at beam current levels two orders of magnitude below the required levels (Section 4.3). New negative ion sources have achieved the necessary peak currents and low beam emittances, but such sources have not been reported to operate continuously. Additional issues are emittance growth of the high current beams in the low energy accelerator sections, and the development of large bore magnetic optics. Power requirements and weight are also significant issues (Chapter 8).

Ionization of the neutral beam atoms via atmospheric collision (and subsequent ion deflection in earth's magnetic field) establishes a minimum operating altitude of about 120 km for beam kinetic energies of a few hundred MeV (Section 4.1).

In order to take advantage of the absentee ratio of a NPB device platform constellation designed for booster kill, NPB devices have been suggested for use in an interactive midcourse discrimination mode (identifying massive reentry vehicles in a postulated threat cloud which includes light weight decoys). In this case the beam power requirements will not change significantly, but the target dwell times may be reduced by a factor of 10-1000, and retargeting rates of $> 10\ \mathrm{sec}^{-1}$ may be necessary. Hence, device issues which will require new ideas and further exploration for this mission are development of rapid retargeting mechanisms using magnetic beam steering and fast accurate methods for beam direction sensing (Section 7.7).

6. **Energetic electron beams require propagation in laser-created plasma channels in order to avoid beam deflection in the earth's magnetic field; this restricts the operational altitude at the low end by beam instability and at the high end by ion density starvation. We estimate that booster kill applications require a scale-up in accelerator voltage by at least one order of magnitude, in pulse duration by at least two orders of magnitude, and in average powers by at least three orders of magnitude. Active discrimination applications require scale-up in pulse duration by at least two orders of magnitude, and in average power by at least two orders of magnitude. The lasers needed for the creation of plasma channels require development. We estimate that propagation distances must be increased by several orders of magnitude.**

Propagation through a laser created plasma channel is necessary to prevent beam space-charge blow-up and beam bending in the earth's magnetic field. This implies both a lower and an upper altitude operational limitations. The lower bound arises from beam stability considerations, while the upper bound results from ion density starvation. This mechanism for beam guiding has been successfully demonstrated in the laboratory, but over distances of 95 meters[8] (Section 4.2). For optimum beam currents of a few kiloamperes, delivering lethal pulses to distances in excess of 1000 kilometers will require beam kinetic energies of several hundred MeV. Useful ranges for some suggested interactive discrimination applications could be as small as a few hundred kilometers, in which case the particle energy requirement would decrease by an order of magnitude (Section 7.7). Existing linear induction accelerators have demonstrated the necessary peak power capability (tens of MeV at peak currents of tens of kiloamperes and pulse repetition rates of a few Hertz), although not for required pulse lengths of microseconds (Section 4.2). Although several approaches have been suggested, the laser technologies required for creating the plasma channel have not been demonstrated. Because of the limited engagement space, rapid retargeting ($\sim$ 0.1 sec) and high repetition rates ($>$ 10 Hz) are essential.

7. **Phase correction techniques are required for obtaining near diffraction limited performance of most types of laser weapon devices. Further, phase control techniques are required for coherently combining outputs from different modules in a multiple laser system into a single diffraction limited beam. These techniques, demonstrated at low powers, must be scaled up by many orders of magnitude in power.**

High power laser systems are likely to require active control and correction of the optical phase of the output beam to reach the nearly diffraction limited performance desired for strategic defense applications. Several techniques are available for these purposes. These include correction of slowly varying phase errors with low spatial frequencies through use of adaptive optics and self-correction of phase errors using nonlinear phase conjugation techniques, such as stimulated Brillouin scattering, or four-wave mixing; and combining beams from multiple apertures by phase locking of multiple laser modules, or through stimulated Raman scattering. Each of the laser technologies under development may use different types of phase corrections. All of these approaches for phase correction have been demonstrated on a laboratory scale, but extensions to high power systems and large apertures remain to be demonstrated (Section 5.4).

8. **Dynamic phasing of arrays of telescopes requires extensive development in order to obtain large effective aperture optical systems. As calculations indicate (Section 5.4.5), the number of phase correcting elements must be increased by at least two orders of magnitude over currently demonstrated values.**

Optical laser systems will require large effective optical apertures in order to achieve the necessary beam intensity on target. Such radiating apertures have to provide near diffraction limited beams which can be rapidly retargeted. The state of the art for ground based monolithic telescope primaries for astronomical applications is about 8 meters.[9] Torque

[8] G. J. Caporaso, F. Rainer, W. E. Martin, D. S. Prono, and A. G. Cole, "Laser Guiding of Electron Beams in Advanced Test Acceleration", *Phys. Rev. Letters* 57, 1591-1594 (1986).
[9] C. H. Townes, private communication.

requirements for rapid steering of large telescopes limit such telescopes to approximately 8 meters aperture; the larger "effective aperture" primaries have to be synthesized by dynamically phasing a number of smaller telescopes. Such phasing of a number of telescopes has been accomplished[10] by dynamically controlling the wavefront "piston", tilt, and focus of the laser beams feeding each telescope of the array. This adds complexity to the system but allows beam pointing in terms of target tracking without requiring slewing of telescopes (Section 5.2).

The phase front of the outgoing wave is monitored in such phasing schemes, and corrections are applied via electrically driven actuators. Components for control of about several hundred such actuators are commercially available. For the large apertures contemplated for BMD applications the number of actuators needed lies between ten thousand and one hundred thousand, a substantial extrapolation. The technology of phase-controlling an array of primary mirrors is in an early stage of development. Scaling of such arrays to high power has not been accomplished (Section 5.4).

An alternative approach is to use telescopes where the primaries are made out of single large flexible membranes which are appropriately distorted by many actuators. The concept has been demonstrated only for small flexible primaries at low powers. Extensions to larger mirrors at higher powers remains to be shown (Section 5.4).

9. The optical coatings of large primary mirrors are particularly vulnerable in space based optical subsystems.

The large primary mirror, which directs the laser beam towards the target, is particularly vulnerable to radiation from other lasers (from any direction) (Section 5.6). Based on dicussions with commercial vendors, we find that the cw power loading threshold for reflective coatings is about 100 kW cm^{-2}. For laser pulses of a few microseconds or less, the damage threshold will be about 8 J cm^{-2} of absorbed energies, corresponding to peak powers of 10 MW cm^{-2}. These damage thresholds are for operation at a nominal laser wavelength of 3 μm (Section 6.2). If attacked by lasers at other wavelengths in the visible, near ultraviolet (UV), or X-ray region, the damage threshold may be significantly lower. Further, there is a possibility of damage to the high reflectivity coatings from energetic particles in the ambient background, i.e. MeV protons and electrons, during long term residence of the high reflectivity mirrors in space.

10. Small secondary mirrors in the optical trains of high power lasers will need very low absorptivity coatings and will have to be cooled.

The requisite power levels for ballistic missile defense lethality will necessitate cooling of the small mirrors in the optical train of high power lasers to prevent damage. A beam power of 1 GW on a mirror of 100 cm^2 area implies an incident power of 10^7 W cm^{-2}. High reflectivity coatings with less than 10^{-4} absorptivity are needed. Such mirrors have been demonstrated, and lead to an absorbed power of 1 kW cm^{-2}. Cooled silicon or silicon carbide mirrors show promise for raising this threshold (Section 5.5).

[10]See references 2 and 3 of Chapter 5.

11. Ground based laser systems for BMD applications need geographical multiplicity to deal with adverse weather conditions.

For each ground based laser system which must be available in battle, a number of geographically separated laser sites are needed to provide availability of at least one site in the system when the others are obscured by adverse climatic conditions. These locations must be separated by distances greater than the coherence length scale for weather patterns. Based on weather statistics, a multiplicity of five independent ground based lasers could provide a 99.7 percent availability. By going to 7 climatically isolated locations in the continental U. S. availability of 99.97 percent is possible. At each of these sites, local cloud cover conditions require further multiplicity of the large ground telescopes, separated by few km (Section 5.4).

12. Ground based laser systems require techniques for correcting atmospheric propagation aberrations. We estimate that these techniques must be extended by at least two orders of magnitude in resolution (number of actuators) than presently demonstrated. Phase correction techniques must be demonstrated at high powers.

Ground based laser systems will require either linear or nonlinear adaptive optics of a very sophisticated nature in order to precompensate the laser beam for atmospheric aberrations caused by atmospheric turbulence and by thermal blooming induced by the laser beam itself. A retroreflector or a low power laser located at an appropriate point-ahead position in front of a space based relay mirror would provide a reference source for transmission through the atmosphere to the ground telescope, where the wavefront would be analyzed for acquired aberrations due to the atmosphere. This analysis would be used to actuate adaptive optics of high resolution ($\geq 10{,}000$ actuators per aperture) at high bandwidths (≈ 1.0kHz). This technique requires an extensive computational capability. Such atmospheric compensation experiments have been successfully demonstrated at low powers (no thermal blooming in the atmosphere) and at average atmospheric viewing conditions for Mt. Haleakala, Maui (moderate turbulence) with a small number of actuators (< 100). At high power levels, the turbulence may be high enough to cause a beam intensity redistribution which could be uncorrectable (Sections 5.2 and 5.4).

The incorporation of phase correction schemes in pulsed induction linac FEL amplifier is particularly stressing because the atmospheric compensation must be carried at high power levels. Atmospheric compensation techniques are needed for point-ahead angles which are large and for targets which may be non-cooperative.

13. Uplink in a ground based laser system faces transmission losses in the atmosphere.

The uplink of high power output from a ground based laser system faces natural atmospheric losses such as Rayleigh scattering, which stress the short wavelength systems, and atmospheric absorption losses, primarily from water vapor, which stress the longer wavelength systems. The optimum wavelength region is $0.4-1.0\ \mu$m. Even in this region, nonlinear effects such as stimulated Raman scattering and thermal blooming force the use of large final transmitting optics on ground (Section 5.4).

14. Nonlinear scattering processes in the atmosphere impose a lower limit on the altitude at which targets can be attacked with a laser beam from space.

Power delivery downward through the atmosphere to rising targets may be limited by stimulated Raman scattering and thermal blooming by ozone absorption. These phenomena limit the minimum attack altitude to 80 km for very short pulses, or require a longer pulselength (1-10 ms), because the laser beam must be focussed to a small, $\sim 1\ m^2$, spot size on the target. At the required high laser intensities, nonlinear effects may throw the optical power out of the focussed beam before reaching the target (Section 5.4).

15. Detection and acquisition of ICBM launches will pose stringent requirements for high detection probability and low false alarm rates.

The achievement of boost phase kill probabilities of 90% implies booster detection and acquisition probabilities of better than 90%. In addition, successful operation of a mid-course system depends importantly on being given good booster trajectory information. Of even greater importance, low false alarm rates are required so that a BMD system is not activated in peace time because of the false alarms (Section 7.2).

16. For boost phase, infrared tracking of missile plumes will have to be supplemented by other means to support sub-microradian aiming requirements of DEWs.

Tracking of missiles by detecting the intense short wavelength infrared (SWIR) radiation from booster plumes is a technology which has been pursued for some time. The plume brightness greatly exceeds that of the missile, and the position of the missile within the plume depends in a complex manner on altitude, missile type, rocket motor, fuel characteristics, etc. and is susceptible to variation by the offense in a manner which cannot be predicted by the defense. Other passive means of accurately locating and tracking missiles in boost phase are in early stages of study (Section 7.5).

Active means of tracking may be required. Of the likely candidates, microwave radars are the most developed although electronic countermeasures for them are also well developed. Optical radars may be more promising, if the illuminating beam can be rapidly retargeted, and if an imaging capability can be achieved (either range-Doppler or angle-angle systems would be sufficient). If rapid retargeting cannot be developed and if power-aperture requirements for microwave radars become too severe hundreds to thousands of space platforms will be needed (Section 7.6).

17. For post-boost and midcourse, precision tracking will require active sensor systems.

Observation of PBV's and RV's (at 300 K) will require detection of weak thermal signatures since these signatures vary as T^4. Similar signatures are associated with objects in midcourse. Thermal detectors in the long wavelength infrared (LWIR) can be used only above the earth's limb against a cold sky background. Low noise LWIR detector assemblies having the appropriate resolution, i.e. large element arrays, are being developed. Because of the long wavelengths involved (8-12 μm), sub-microradian tracking accuracy is not feasible in LWIR without using telescopes with apertures in excess of ten meters (Section 7.2). Thus, thermal detectors will have to be supplemented by some active means such as microwave or optical radars. A large number of space-based platforms will be required. These might be the same platforms that are performing similar duties in the boost phase (Section 7.3).

18. For midcourse, when the RVs are interspersed with penetration aids, interactive discrimination may be required. At present the application of DEW technologies to this task is in the conceptual and early experimental stage.

Missiles which survive the boost phase can deploy large numbers of decoys and other penetration aids. Since LWIR and radar signatures depend largely on surface phenomena, there are many options available to the offense desiring to confuse or saturate the defense (use of balloons for example). Directed energy technologies may offer the possibility of "mass" discrimination by interactive, perturbing means, e.g. detection of particle-beam-induced secondary emissions or velocity changes caused by laser-ablation-induced impulse. DEW platforms absent from the boost phase intercept theater might be useful in this function. Such interactive discrimination is in a conceptual and early experimental stage, and would require large numbers of additional sensor/detector platforms, plus the ability to function in nuclear-disturbed backgrounds (Section 7.7).

19. The development of an effective boost phase defense is highly desirable, perhaps essential for limiting the number of objects with which the midcourse and terminal defense elements must cope.

Given the present number of Soviet boosters and their capability, the offense can deploy half a million or more threat objects (reentry vehicles and decoys). Boost phase attrition is required if midcourse discrimination systems can deal with only a limited number of threat objects. Even a 80% effective boost phase defense would leave 100,000 or more objects entering the midcourse phase. If further increases in the offensive threat or degraded performance of the boost phase tier overload the tracking and discrimination capabilities of later tiers, then the overall performance of the defensive system would degrade catastrophically rather than linearly when saturation is approached. The tracking and discrimination of tens to hundreds of thousands of objects during the midcourse phase poses formidable challenges to sensors and battle management computers. If discrimination requires birth-to-death tracking of all threat objects, these problems become even more demanding (Section 2.3).

20. House-keeping power requirements for operational maintenance of many space platforms for strategic defense applications necessitate nuclear reactor driven power plants on each of these platforms.

The power requirements for "house keeping", i.e. the requirements for a space platform to control attitude, to cool mirrors, to receive and transmit information, to operate radars, etc. is estimated to be in the range of 100-700 kW of continuous power. This would require a nuclear reactor driven power plant for each platform, necessitating perhaps a hundred or more of these nuclear reactors in space. These foregoing needs require solving many challenging engineering problems not yet explored. Cooling of large space-based power plants is a very difficult task (Chapter 8).

21. During engagements prime power requirements for electrically driven space based DEW present significant technical obstacles.

The prime power required for electrically driven DEW, e.g., particle beam accelerators, is estimated to be 1GW. This power could be provided by large chemical or nuclear rocket engines and generators, deployed at considerable distances or otherwise decoupled from the DEW platforms in order to avoid mechanical disturbances and effects of exhaust gases. This may require complex power transfer systems comprising cables, microwave systems, etc. Correspondingly, chemical fuel consumption would be more than five tons per minute of operation per platform (Section 8.3).

22. **Survivability is an essential feature of any BMD system employing space-based assets: such survivability is highly questionable at present. Evaluation of these issues requires a systems approach that includes hardening, active defense, and operational tactics. During the deployment phase, the space based assets are especially vulnerable.**

The space platforms carry sensors, optical mirrors, or radar dishes, many of which have considerably lower damage thresholds than do the hardened boosters, post boost buses, and RVs. While sensors and optical mirrors on satellite platforms may be shielded during long periods of inactivity, they would be exposed when put on alert prior to an impending ICBM attack. Such an attack could be preceded by an attack on these platforms by space based and ground based DEW, space based kinetic energy weapons (KEW), space mines, or direct ascent nuclear and non-nuclear anti-satellite (ASAT) weapons of the offense. Moreover, the system must be developed by a process of accumulation of space assets while the system is less capable of defending itself (Sections 9.3 and 9.4).

The ground based laser systems for strategic defense applications require a substantial number of space based optical elements and space based sensors. The space based optical elements include telescopes with large primary mirrors, the size and numbers of which will depend on the basing modes for the relay and the fighting mirrors. These space based elements entail the same vulnerability as any other space based components (Section 9.3).

23. **Survivability of ground based facilities also raises serious issues. The relatively small number of large facilities associated with ground based laser sites makes these facilities high-value targets.**

The ground based laser BMD facilities must be successfully protected from direct attack from many threats (e.g., cruise missiles, sabotage, etc.), in addition to ballistic missiles. Thus, any strategic defense system depending on ground based lasers, or on other ground based facilities which can not be extensively proliferated, must be effective in defending against more threats than just ballistic missiles (Section 9.3).

24. **Directed energy weapons with capabilities below those needed for many ballistic missile defense applications can threaten space based assets of a defensive system.**

If a DEW falls short of ballistic missile defense requirements, it may still be a credible threat to space-based assets. Space-based platforms move in known orbits and can therefore be targeted over much longer time spans than ballistic missile boosters, post-boost buses or re-entry vehicles. The defense platforms may have key components that are more vulnerable than the boosters and the re-entry vehicles. Furthermore, space-based platforms in low earth orbits can be attacked from shorter ranges than those required for boost phase intercepts (Sections 9.3 and 9.6).

25. X-ray lasers driven by nuclear explosions, would constitute a special threat to space based sensors, electronics, and optics.

The high energy-to-weight ratio of nuclear explosive devices driving the directed energy beam weapons permits their use as "pop-up" devices. For this reason the X-ray laser, if successfully developed, would constitute a particularly serious threat against space based assets of a BMD (Sections 3.5 and 9.3).

26. Since a long time will be required to develop and deploy an effective ballistic missile defense, it follows that a considerable time will be available for responses by the offense. Any defense will have to be designed to handle a variety of responses since a specific threat can not be predicted accurately in advance of deployment.

A thorough understanding of practical responses, such as attacks on the defensive assets, hardening of offensive systems, and rapid deployment of large number of decoys, must be established before conclusions about the technical feasibility and cost-effectiveness of a defensive system can be made. A DEW system designed for today's threats is likely to be inadequate for the threat that it will face when deployed (Section 2.3 and Chapter 9).

The American Physical Society

PRESS RELEASE

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FOR RELEASE, NOON
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FEASIBILITY OF DIRECTED ENERGY WEAPONS FOR SDI IS EXAMINED

The development of an effective ballistic missile defense utilizing directed energy weapons (DEW) would require performance levels that vastly exceed current capabilities, according to a panel of experts on directed energy technology convened by The American Physical Society. In a report released today entitled "THE SCIENCE AND TECHNOLOGY OF DIRECTED ENERGY WEAPONS," the study group concludes that insufficient information exists to decide whether the required performance levels can ever be achieved.

The study was headed by Dr. C. K. Patel of AT&T Bell Laboratories and Professor Nicolaas Bloembergen (Nobel laureate) of Harvard. Professor Val Fitch (Nobel laureate) of Princeton, President of the American Physical Society, announced the release of the report.

Directed energy weapons, which include high intensity lasers and energetic particle beams, have been expected to play a crucial role in the Strategic Defense Initiative. The study group estimates that, "even in the best of circumstances, a decade or more of intensive research would be required just to provide the technical knowledge needed for an informed decision about the potential effectiveness and survivability of directed energy weapon systems."

This would still have to be followed by extensive development in many important technological areas. The Soviet Union can be expected to use the time to make their missiles less vulnerable to such weapons and to develop the means to attack the defensive system.

The report cautions against forcing an immature technology into an engineering evaluation. This would tend to freeze the technology at levels inadequate for its ultimate goals and absorb resources that could otherwise be used for research on more promising approaches. The discrepancy between the present state of the art of DEW and the ultimate requirements is so large that major gaps in technical understanding would have to be closed before engineering evaluation would be useful.

A complete discussion of the background of the study, including the composition of the Study Group and the APS Review Committee, is included in the press packet.

This is the only major independent study to concentrate on the physical basis and technical feasibility of directed energy weapons. Although the study was supported entirely from private sources, the cooperation of the Strategic Defense Initiative Organization was sought and received, including classified technical briefings of the study group.

The report of the 18-month study was submitted to SDIO for national security review on 25 September 1987. Authorization to release the amended report was finally received on 10 April 1987. The report was formally adopted by the APS Council on 21 April 1987 on the recommendation of the APS Review Committee.

The report does not discuss kinetic energy weapon technologies nor does it address the complex issues associated with battle management, including the testability and reliability of the software. The related issues of arms control and strategic stability are also beyond the scope of the report.

The immense size of the technological development of DEW, let alone deployment, raises questions about economic cost and the diversion of technical manpower from other national needs. Although the study group believes these are important issues, it refrains from conclusions about them. The report does note, however, that the deployment of any ballistic missile defense system with extensive space-based components will require that the cost of placing objects in space be significantly reduced. If such major cost reductions can be achieved, it must be assumed that opponents can realize the same reductions, thus enabling them to increase their offensive threat.

SOME MAJOR CONCLUSIONS OF THE STUDY:

ALL EXISTING CANDIDATES FOR DIRECTED ENERGY WEAPONS REQUIRE IMPROVEMENT BY A FACTOR OF AT LEAST 100 IN POWER OUTPUT AND BEAM QUALITY BEFORE THEY CAN BE SERIOUSLY CONSIDERED FOR APPLICATION IN BALLISTIC MISSILE DEFENSE SYSTEMS.

Infrared chemical lasers have been under study for the longest period of time, but their long wavelengths and other technical features limit their usefulness for a ballistic missile defense. The power levels of hydrogen fluoride and deuterium fluoride chemical lasers would need to be increased by a factor of 100 to satisfy even the least demanding strategic defense applications. For atomic iodine lasers, power levels would need to be 100,000 times present levels. Free electron lasers and excimer lasers are currently considered to be better candidates for strategic defense applications. However, few high power laboratory models have been operated, and the problems of scaling up to relevant power levels is estimated to be greater than for chemical lasers. Nuclear explosion pumped X-ray lasers, although the subject of much public discussion, require experimental verification of many physical concepts before their application to strategic defense can be evaluated. Charged and neutral particle beam devices build on an existing base of accelerator technology but would require considerable improvement beyond current performance levels.

PROPOSED SUPPORTING TECHNOLOGIES NEED TO BE SYSTEMATICALLY STUDIED BEFORE THEIR PERFORMANCE AT LEVELS APPROPRIATE TO BALLISTIC MISSILE DEFENSE APPLICATIONS CAN BE REALISTICALLY EVALUATED.

In many areas of supporting technologies, research is progressing at a rapid pace--for example, schemes for rapid steering of optical beams and active systems for tracking with great accuracy. However, atmospheric effects and weather problems of ground based systems, susceptibility of optical systems to damage, power requirements for space based systems, decoy discrimination, launch detection, and precise tracking technologies all present problems for which solutions do not now exist.

OFFENSIVE RESPONSES DURING THE PERIOD OF DEVELOPMENT AND DEPLOYMENT OF A BALLISTIC MISSILE DEFENSE WILL BE EVOLVING TO MEET THE THREAT.

In many cases the options available to the offense may be less difficult and less costly. A thorough understanding of practical responses, such as attacks on the defensive system, hardening of the missiles, and use of decoys, must be established before conclusions can be reached about the technical feasibility and cost-effectiveness of a defensive system can be made. A DEW system designed for today's threats is unlikely to be adequate for the threat it will face when deployed.

THE SURVIVAL OF SPACE-BASED COMPONENTS OF DEW SYSTEMS IS PROBLEMATIC, AND EVEN GROUND BASED COMPONENTS WOULD BE THREATENED.

In addition to all other conventional threats, a deployed DEW defensive system might itself be faced with offensive directed energy weapons.

<u>REPORT OF THE APS REVIEW COMMITTEE:</u>

The APS Review Committee, headed by Dr. George Pake of the Xerox Corporation, acknowledges that security review resulted in small but significant deletions from the Report. In particular, some of the countermeasures available to the offense could not be discussed in detail. They believe, however, that the Report "performs a significant service to APS members and to the general public by providing an authoritative technical background and relevant technical assessments."

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FOR IMMEDIATE RELEASE

APS STATEMENT URGES
NO EARLY COMMITMENT TO SDI DEPLOYMENT

New York, NY--: Dr. Val Fitch, President of The American Physical Society (APS), today announced the release of a public statement adopted by the APS Council, the governing body of APS, that urges no early commitment to the deployment of Strategic Defense Initiative (SDI) weapons. (Full text of statement attached.) The APS is the the nation's largest organization of physicists whose members would provide the scientific foundation for SDI weaponry. The APS statement notes:

> In view of the large gap between current technology and the advanced levels required for an effective missile defense, the SDI program should not be a controlling factor in U.S. security planning and the process of arms control. It is the judgment of the Council of The American Physical Society that there should be no early commitment to the deployment of SDI.

The Council's statement follows the release last week of a major APS study that addressed directed energy weapons (DEW), the group of particle and laser-beam systems that would form the main weapons of SDI. One of the main conclusions of the DEW Study was that, "A decade or more of intensive research would be required to provide the technical knowledge needed for an informed decision about the potential effectiveness and survivability of directed energy weapons." The current APS statement goes beyond specific DEW issues and gives a broader, more comprehensive comment on SDI.

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4/24/87

THE AMERICAN PHYSICAL SOCIETY ISSUES

STATEMENT ON THE STRATEGIC DEFENSE INITIATIVE

The Council of the American Physical Society, at its meeting on 24 April 1987, adopted the following statement on the Strategic Defense Initiative (SDI). The Council Statement on SDI is separate and broader than the subject matter and the conclusions of the DEW Study report.

APS COUNCIL STATEMENT ON THE STRATEGIC DEFENSE INITIATIVE

A major study of the science and technology of Directed Energy Weapons (DEW), conducted by a study group of the American Physical Society, found that:

- The development of an effective ballistic missile defense utilizing DEW would require performance levels that vastly exceed current capabilities.

- There is insufficient information to decide whether the required performance levels can be achieved.

- A decade or more of intensive research would be required to provide the technical knowledge needed for an informed decision about the potential effectiveness and survivability of directed energy weapon systems.

- The important issues of system integration and effectiveness depend critically on information that does not now exist.

The Council of the American Physical Society believes that it has a public responsibility to express concerns about the Strategic Defense Initiative that go beyond the issues of DEW covered in the Study:

1. Even a very small percentage of nuclear weapons penetrating a defensive system would cause human suffering and death far beyond that ever before seen on this planet.

2. It is likely to be decades, if ever, before an effective, reliable, and survivable defensive system could be deployed.

3. Development of prototypes or deployment of SDI components in a state of technological uncertainty risks enormous waste of financial and human resources.

In view of the large gap between current technology and the advanced levels required for an effective missile defense, the SDI program should not be a controlling factor in U.S. security planning and the process of arms control.

It is the judgment of the Council of the American Physical Society that there should be no early commitment to the deployment of SDI components.

STRATEGIC DEFENSE INITIATIVE ORGANIZATION COMMENTS
ON THE
AMERICAN PHYSICAL SOCIETY
REPORT ON
DIRECTED ENERGY TECHNOLOGY

The Strategic Defense Initiative Organization (SDIO) is pleased that the American Physical Society (APS) has responded to the President's challenge to the scientists and engineers of the United States to join together to seek defensive solutions to the ballistic missile threat. The APS report offers a challenge to the APS membership to help us seek innovative solutions to the technical issues we must resolve to develop effective directed energy weapons technology for strategic defense.

Although the chapters in the report prepared by individual panels represent an objective independent appraisal of various technologies, we find the conclusions to be subjective and unduly pessimistic about our capability to bring to fruition the specific technologies needed for a full-scale development decision in the 1990's.

The report has the additional problem of being a "snap-shot-in-time" that dates to the preparation of the report. We have made significant progress in the intervening period. In fact, some technologies have shown several orders-of-magnitude increase in performance.

While the APS study group has achieved an impressive compilation of unclassified source material and, as one wold expect, astutely applied physical principles in their analysis, we would not have made several of the assumptions they made in defining the technical requirements.

Specific examples:

1. With respect to the free electron laser (FEL), the report states that "scaling to short wavelengths at high powers is more difficult problem than simply increasing average power."

o During the period over which the report was being prepared we have operated our FEL in the visible light spectrum.

o Scaled the FEL down in wavelength by a factor of 800 (almost three orders of magnitude).

o Improved the brightness of the electron beam injector for the FEL by two orders of magnitude.

2. With respect to the neutral particle beam (NPB) program, the report states that "NPB accelerators...must be scaled up to two orders of magnitude in voltage and duty cycle," and further, "ion sources...have not been reported to operate continuously."

o In fact, we have demonstrated a continuous wave ion source that produces 50 percent more current than required and has already met our beam quality goals.

o A demonstration on the 5 Mev (Million Electron Volt) accelerator test stand at Los Alamos National Laboratory that the full beam current can be produced and accelerated with no significant emittance growth.

o The remaining issue of scaling up from 5 Mev to higher energies is now a modest extrapolation of beam accelerator technology.

-END-

Physicist confident of SDI technology

By KAREN MacPHERSON
Tribune Washington Bureau

WASHINGTON — It's impossible to say how long it would take to develop the technology for the proposed "Star Wars" program, says an Albuquerque physicist who worked on a new report studying the anti-missile system.

But Petras Avizonis, the technical director of the lasers and optics division at the Air Force Weapons Laboratory, also said that the report released by the American Physical Society showed that the program was feasible.

"What I found significant about the report was that, even though everybody agreed there was a tremendous amount of development and engineering difficulty ... there was no basic science that said you cannot do it," Avizonis said in an interview Friday.

"With enough resources and time, there is nothing that says you are violating some fundamental laws that would cause you to fail."

But Avizonis also said that, because of the "different levels of maturity" of the various components needed for the formally-called Strategic Defense Initiative, it's impossible to predict how long it will take to develop the technology for it.

"To say that it takes 10 years or whatever to finish developing the technology — that's kind of a tremendous overgeneralization," he said.

"It may take longer, it may take a lot less, depending on the level of maturity. You have to go item by item and we really did not try to do that in any great detail in the report," Avizonis said.

Avizonis was part of a 15-member panel of military and civilian scientists created by the American Physical Society to study the energy-directed weapons that are critical elements of the SDI program.

Avizonis said he particularly worked on a chapter in the 424-page report dealing with beam control.

Two physicists at the Sandia National Laboratory — Robert Clem and Bruce Miller — also were members of the panel, considered to be a collection of the nation's leading physicists.

Asked whether he believes the SDI program is a good idea, Avizonis replied: "We should do it if it is effective.

"The problem is that we don't know until a lot more work is done whether it can be effective," Avizonis said.

Once the technology is developed, Avizonis said, then U.S. officials must ask themselves a series of questions, including what is it going to cost, is it going to be cheaper for the Soviets to overcome it than for us to build more of it and is i[t] going to be survivable.

"What I see right now is tha[t] we are basically in the technolo[gy] development activity. We'v[e] got to do that before we ca[n] answer any questions. After tha[t] the decision has to be made o[n] the basis of effectiveness an[d] utility.

"Technology is like a gat[e]. Once you pass through the gat[e] then you can make your dec[i]sion. Our report addressed wha[t] it would take to get through tha[t] gate," Avizonis said.

COMMENTS ON THE REPORT OF THE

AMERICAN PHYSICAL SOCIETY

Frederick Seitz

As you know, Dr. Lowell Wood and I are here today to comment on the report derived from the study of the Strategic Defense Initiative carried out by a group of distinguished physicists under the sponsorship of the American Physical Society. This report has apparently taken on the status of the official opinion of the Governing Council of that very large scientific society.

As you will note from my brief professional summary, I have served as President of the American Physical Society, President of the National Academy of Sciences, Chairman of the Defense Science Board and Science Advisor to NATO. I am currently serving as Chairman of the Science Advisory Committee for SDI. I have held various academic positions, most recently as President, and now President Emeritus, of Rockefeller University.

In a few minutes Dr. Lowell Wood will review for you the scientific merits and technical accuracy of the report by the APS panel. A distinguished roster of American scientists contributed to the report, as panel members or members of the Review Committees. The product of their endeavors was released to the public by the Council of the American Physical Society as an important contribution to the national debate over the best means of ensuring the survival of the American nation.

In my view, however, this report is not worthy of serious consideration in that vital debate. This may seem like an unduly severe indictment of a document bearing the seal of approval of one of the nation's most distinguished scientific bodies. Yet I know of no other way to describe a nominally serious study, replete with equations, which nonetheless contains numerous errors, inconsistencies and unrealistic assumptions on matters of great importance in the technological assessment of missile defenses.

The mistakes in the report are not small. They are major errors, by factors of as much as 100-fold. Furthermore, these errors and inaccuracies are, as far as we can tell, always in one direction -- such as to make the plan for defending the American people -- indeed the people of the free world -- against a Soviet nuclear attack seem more difficult than it really is.

I make this judgment on the report of the APS panel from the perspective of more than half a century of membership in the American Physical Society, and past service as a president of the Society and member of its Governing Council. I know of no precedent, in my long association with the American Physical Society, for the issuance of so seriously flawed a document as this, under the aegis of that Council.

The report is to be published in its present form this summer, without accompanying criticism by other member physicists, in one of the official journals of the Society, namely, THE REVIEWS OF MODERN PHYSICS. When I became aware of the deficiencies in the APS report, I spoke with the editor of the journal in which it is to be published, regarding the importance of simultaneous publication of a scientific paper containing a critical examination of the report's contents. I came away from that conversation with the impression that timely publication of a paper criticizing the report of the APS panel was not likely under APS auspices.

What we seem to see at work here is a lowering of the standards of publication in the journals of one of our most respected scientific organizations, in regard to to an important defense program that happens to be unpopular with a number of American physicists. Such a degradation of the standards of publication of scientific journals is a very serious matter, with ominous implications for the health of the American scientific community and the welfare of our nation.

Physicists with long memories will recall that when the Nazis came into power in Germany in the 1930s, the German physics journals -- which had been, until then, among the finest in the world, as the journals of the American Physical Society are today -- began to publish work of questionable quality. That was one of the earliest indications of the decline of German science in the pre-World-War II period. One thinks also of the unfortunate depths to which some Soviet scientists, especially in genetics, have descended at various times to satisfy the prevailing currents of political thought in the Soviet Union.

I cannot fail to note also that the Executive Summary of the APS report, which purports to be an accurate summary of this report's findings, is inconsistent with the body of the report in numerous respects. Furthermore, the inconsistencies are always in a direction that makes the Executive Summary more negative and pessimistic than the technical analysis in the report itself would warrant.

And then one notes that a public statement released by the Council goes beyond even the Executive Summary of the report, in expressing still more negative and pessimistic statements about the prospects for defending the American people from Soviet missile attacks. This statement by the Council is twice removed from the technical facts. Indeed, the Council's statement abandons all pretense of being based on scientific factors; it explicitly states that its comments go beyond the limits of the technical report of its panel.

As I contemplate these successive changes -- from the technical report iself, with its honest, if flawed, attempts at a proper scientific study, to the more negative and pessimistic

Summary of the report, and then to the extremely negative statement by the APS Council, with its harsh dismissal of all efforts at an American defense against ballistic missiles --I cannot help but conclude that these actions by the Council of the American Physical Society represent a political as well as a scientific declaration.

Personally, I believe that scientific societies and academies serve the fields of science and the nation best when they do all they can to avoid taking political positions on national issues. Scientists in our open countries should treasure the freedoms they have and devote their societies to purely scientific affairs. There are other avenues for expressing political views.

I am pleased now to present Dr. Wood, who will review the technical content of the APS report.

Joint Opening Statement Of

Drs. Lowell Wood* and Gregory Canavan*

Before The House Republican Research Committee
19 May 1987

Introduction and Background. We certainly appreciate the opportunity to appear before you today for the purpose of clarifying the role of directed energy in strategic defense. We are privileged to appear in such distinguished company as that of Professor Frederick Seitz, former President of Rockefeller University, former President of the American Physical Society, former President of the National Academy of Sciences, and one of the most eminent members of the American physics community.

Between the two of us, we have nearly a half-century of professional experience, working full-time in the technical areas underlying strategic defense, including all of the areas treated in the recently published Report of the American Physical Society's Study Group on Directed Energy Weapons; several aspects of our work have been recognized with national awards and prizes. Our experience is recent, as well as broad; we continue to be engaged full-time in such research activities through the present time.

The two of us are working on strategic defense research because we believe that the chances are quite reasonable for achieving the basic goal of an effective defense against attack with nuclear-tipped ballistic missiles, moreover during the next decade and at moderate cost compared to other major defense programs.

We would like to remark at the outset that we were puzzled by the press coverage surrounding release of the Report of the APS Study Group on Directed Energy Weapons. According to the press, the Report was quite pessimistic about the prospects for using lasers and particle beams to destroy hostile missiles aimed at the United States or its Allies. The *New York Times*, for example, headlined its front-page story on the Report, "Physicists Express 'Star Wars' Doubt; Long Delays Seen."

We were therefore quite puzzled by the fundamental difference between our findings regarding the new technologies of missile defense and those attributed to the APS Study Group. Facts are facts; physical law is physical law. Why should two groups of physicists, using the same facts and proceeding from the same physical laws, arrive at such different conclusions? Particularly perplexing to us was the implication that several authors of the Report, who are colleagues of ours and who have also invested many years of their personal effort in SDI-related research but who have not previously expressed disillusionment with directed energy weaponry to us, would take the positions expressed in the Report, especially its Executive Summary.

Thus, we took a look at the APS Report to try to reconcile its findings with our knowledge of this field.

Almost immediately, we found large errors in critical aspects of the Report—errors of factors of 10 to 100 on vital matters such as the power of the laser beams being developed by SDI research teams. These errors didn't have a random character; they were all in the direction of making a defense against Soviet ballistic missile attack seem harder than it really is.

**The speakers are, respectively, technical staff members of the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory. They are not appearing in any official capacity from either of their Laboratories, and the opinions they express are not necessarily those of anyone other than themselves.*

There were also blatant inconsistencies between the Executive Summary of the Report and the more detailed sections in the body of the Report. The Executive Summary—which the press necessarily relied upon and which the APS Council highlighted in its press release—was nearly always more negative about the technical prospects for SDI than was the body of the Report, which contained all the physics and the associated technical arguments. Indeed, *the Executive Summary stated conclusions and rendered judgments which had no basis in the body of the Report.* This reflects poorly on what is assumed to be some majority of the Report's authors, and severely detracts from the serious, if flawed, efforts to identify and discuss technical issues in the body of the Report.

We would like to share with you in summary our findings regarding the most important errors in the APS Report and the most notable inconsistencies between the body of the Report and its own Executive Summary. These are treated more comprehensively and in greater detail in the accompanying document authored by one of us, "Directed Energy Concepts For Strategic Defense," (LA-UR 87-1658, May 1987). This document also provides what we feel is a balanced and generally positive evaluation of the roles that directed energy concepts could play in strategic defense and of the technical progress being made toward evaluating them on the time-scales in which their contributions might be needed.

Laser Power Levels. The first specific item in the Executive Summary (on p. 4) states that chemical lasers have only been tested in the SDI program at a power level somewhat above 200,000 watts. It then states that the power of these lasers must still be increased by a factor of at least 100 to be useful against Soviet missiles, meaning that the laser beam power must be raised to more than 20,000,000 watts.

But SDI has already tested a laser with a beam power at the multi-million-watt level. It did so more than a year ago. In fact, the Report itself acknowledges this fact on p. 60. (Of course, due to the rapidly evolving mission for chemical lasers, no single device has simultaneously demonstrated the power, efficiency and beam qualities required for strategic defense applications; however, there is no question that the present state-of-the-art is less than one, rather than two, orders-of-magnitude away—less than a factor of ten, rather than a factor of one hundred—from the requirements for strategic defense utility.)

What is one to make of a Report that contradicts its own Executive Summary on one of the single most critical points in the entire Study?

Furthermore, Soviet scientists working on their own 'Star Wars' program had lasers operating at million-watt levels much earlier than did SDI, another fact well-known to at least some of the authors of the APS Study. It is reported that, when asked in the Geneva negotiations about these ultra-powerful lasers located in one of their major weapons labs, the Soviets said that they were for medical research. This was said about lasers that could blow a one-foot diameter hole through the human body in about a second!

Why did the APS Report talk in its Executive Summary about SDI testing of lasers at powers of 200,000 watts, when its authors documented their knowledge in the Report's body of SDI testing of lasers with beam powers of millions of watts? Why did the Summary—which is all that most reporters would read—contain *a factual error of a factor-of-ten* in laser power levels *in its very first and most prominent item*, moreover an error in a direction that makes the defense against Soviet missiles seem to be farther off than it really is?

Furthermore, the Study Group had been authoritatively informed that a laser with a power level of 5 million watts, working with a 4 meter mirror, would be very effective in destroying at high rates all the current generation Soviet missiles—a laser with a beam power level less than a factor-of-three greater than that *already demonstrated* in the SDI program. (This issue is explored in detail in the accompanying LA-UR document, e.g., on p. 64.) It is puzzling that this salient fact wasn't mentioned at all in the Report.

Then there is the matter of the excimer laser, a different type of laser technology that delivers its energy in intense pulses, each one administering a sharp blow to the target. It is very difficult to protect a target from destruction by the rapid succession of sledge-hammer blows created by impingement of intense excimer laser pulses. Indeed, even a single sufficiently energetic excimer laser pulse, perhaps of less than a thousandth of a second in duration, will blow apart even a hardened missile.

The APS Report says that the excimer laser must be operated a a power level of *one billion watts* to be an effective weapon in defending the United States from ballistic missile attack. As the justification for this enormous power requirement, it cites formulas for the necessary "lethality" of the excimer laser—the amount of energy necessary to punch a hole in a missile's skin with these sledge-hammer blows.

But when the APS Report's *own* numbers are inserted in its *own* lethality formulas, given in the Report on p. 270, the formulas yield a power requirement of *six million watts*, not *one billion watts*, as stated by the Report's Executive Summary. (Again, these calculations are presented in detail in the accompanying LA-UR document.)

This is an error of a factor of 160. Once again, this huge error is in a direction that makes the challenge of building an effective defense seem more daunting than it actually is.

Neutral Particle Beams. Then there is the matter of neutral particle beams, and particularly the question of how to supply the necessary power to them. This is a very important issue, because the neutral particle beam has the promise of being an exceedingly valuable weapon in a strategic defense system.

What is a neutral particle beam weapon? It generates a beam of fast-moving atoms, each so energetic that it can penetrate deep into the interior or a missile or a warhead. If such an atomic beam is sufficiently intense and energetic, it can cause an explosion that destroys the rocket or the bomb. Even if it is far less intense, it can still lethally disrupt the functioning of the electronic control circuits in the missile or warhead.

Disrupting the operation of such electronic circuitry may well be just as effective as destroying the entire target outright, such as in an explosion. If the target is a missile, disturbing its electronics addles the missile's brain, for instance preventing its guidance or rocket engine control systems from working properly. As a result, the missile may swerve off course and break up, or even explode. If the missile survives attack, the neutral particle beam, directed against the "bus" that sits on top of the booster and carries the warheads, will penetrate into its interior and confuse or destroy the computer which controls the aiming and release of the bus's warheads. As a result, the warheads may leave the bus with the wrong direction or at the wrong time, so that they fail utterly to reach their targets, or they may fail to leave the bus at all.

Finally, if both the missile and the bus it carries somehow get through the defense, and the bus succeeds in deploying its warheads, the neutral particle beam can still very effectively attack the warheads themselves. The nuclear explosive inside the warhead can only explode after an electronically timed sequence of events has taken place, and disrupting the work of these internal circuits prevents that from happening. The nuclear weapon has been effectively disarmed.

Because the neutral particle beam is potentially capable of destroying or disabling the missile, its bus and the warheads themselves, it is a triple-threat weapon, an extremely promising device for our defenses.

That is why the question of the power needed to operate a neutral particle beam weapon is so important; it is one of the few major technological questions remaining in this area.

The APS Report says that this device also needs *one billion watts* of power to be an effective defensive weapon. However, it is easy to see that this number is seriously in error.

Here is how to obtain the correct answer for the required power for a neutral particle beam system. The beam is being designed to produce 100,000,000 volt atomic particles with a current of one-tenth of an ampere. From elementary physics, watts = volts x amperes. Multiplying 0.1 amperes by 100 million volts give 10 million watts for the power of the beam coming out of this device. For every watt of beam power that comes out, about 3 watts of electrical power has to be put in, which means that 30 million watts of electrical power has to be supplied to run this device. (Once again, details are provided in the accompanying LA-UR document, on pp. 24-25.)

So thirty million watts is the requirement for an effective neutral particle beam weapon. But the APS Report stated that one billion watts would be needed, roughly a factor of 30 larger than the right answer. Interesting enough, 30 million watts of in-space electrical power generation capability is well within reach from existing technology, while a billion watts is definitely not. As before, this APS Study error by a factor of thirty is in the direction that makes defending the U.S. against Soviet missile attack seem harder that it really is.

Free-electron lasers are also criticized in the APS Report for needing large amounts of power. But the 4 million watt free-electron laser equivalent in defensive performance to the largest chemical laser under active consideration requires only 10 million watts of electrical power, not the 1000 million watts estimated in the APS Report. This is yet another of the 100-fold errors in the Report, again in the pessimistic direction.

In-Space Power Supply. Then there is the somewhat more general question of the "housekeeping" power needed to operate U.S. defensive satellites. "Housekeeping" power includes the electricity needed to keep the satellite's temperature at a reasonable level, to run its computers, operate its radio transmitters and receivers, and so on.

The APS Report says (on p. 11) that 100 nuclear reactors would have to be put into orbit to provide "housekeeping" power for the 100 satellites that would compose the heart of the defensive architecture which it hypothesized. This prediction depends critically on an *ad hoc* assumption made by the Study's members, namely that satellite housekeeping requires between 100,000 and 700,000 watts of electrical power. Providing a continuous supply of this much electrical power in space might indeed require the use of a nuclear reactor.

However, the power needed for satellite housekeeping is not hundreds of thousands of watts, not for *any* of the satellites considered in *any* of the "baseline architectures" by the SDI program. Rather, the required power is typically a few thousand watts, a hundred times less than the value asserted (with no reference given) by the APS Report. Even the largest satellites considered in the SDI baseline architectures use little over 10,000 watts—for powering their computers.

These relatively modest power levels—about what an average household uses—are routinely supplied to a satellite by solar photovoltaic cells on the sunlit side of its orbit, and by storage batteries on the dark side. The requirements of even the largest satellites contemplated by SDI baseline architectures—the ones under serious consideration—are within the capacity of currently operational in-space solar power supplies.

Why and how did the APS Report overstate by a factor of 10-100 in the housekeeping power requirements of defensive satellites? It mentions the power needed to operate radars on the satellites, and indeed a radar unit can require a lot of power—but the SDI has no plans for radars on *any* of the satellites in *any* of its baseline architectures. The APS Report also mentions the power needed to cool mirrors—but these mirrors only need cooling during the few minutes' duration of the actual battle and, even in that brief interval, the cooling is accomplished by circulating fluid through the mirrors, a process that doesn't require major amounts of electrical power.

Why did the author of the Executive Summary of the APS Study assume that a defensive satellite would require hundreds of thousands of watts of electrical power, when a minimal acquaintance with space operations would indicate that military satellites normally use far less power than this? If the author thought that radars on the satellites might use that much power, he could have checked with senior SDIO staff to see if such radars were being considered in the baseline architectures. With the classified access which APS Study members enjoyed to SDI program details—as a matter of fact, even without it—they could have confirmed that no such radar usage is planned. Similarly, if the Executive Summary author thought that the cooling of laser mirrors required a great deal of electrical power supply, he could have checked that assumption by inquiring as to how SDI technologists intend to cool these mirrors. He would have thereby discovered that mirror cooling requires essentially no electrical power.

One develops the impression that there is a certain pervasive carelessness in the Executive Summary of the Report. We could find the in-space power supply conclusions in the Executive Summary on p. 11 supported by material *nowhere* in the Report's body, and certainly not with any satellite power requirements budget stated. It is a conclusion which is notable—but by no means unique in the Executive Summary—for having just floated in from nowhere, with numbers not documented anywhere else in the Report.

Another notable example of a certain *qualitative* detachment from reality in the Executive Summary is the technical reference (footnote 7) cited in support of the conclusions regarding x-ray lasers on pp. 5-6. All of the Study's members briefed on x-ray lasers knew that the particular reference cited is perhaps the preeminent example in the published literature of having ludicrously "missed the mark" in analysis of the x-ray laser's potential military utility. Yet there it is, cited *twice* as *the* technical undergirding of the Study's conclusions in this area.

It seems remarkable to us that all of these substantial errors and inaccuracies, often by factors of 10 and more, are in the direction that makes the job of defending the United States against missile attack seem harder than it actually is. All these errors could have been removed by careful checking of data and assumptions, but none of them were. Why did a group of outstanding physicists not check their results and conclusions more carefully before they published their Report?

Perhaps a part of the reason is that the Study Group members had a certain mindset about strategic defense beforehand; perhaps their intuition told each of them that the job was very difficult, maybe even impossible. Now there is a standard practice in physics, and indeed in all fields of technical research: stop periodically; check your calculations and then test them against your intuitive understanding of the problem; if the results do not satisfy your intuition, check them carefully again and then examine your intuition; only if they do correspond to your intuition about what is right, proceed. Perhaps, when errors crept into the Study Group's work—of the kind which can enter into any scientific study, particularly one as complex as that of strategic defense—its members did not check carefully enough to find these errors, because their results were in agreement with their intuitive feeling that missile defense was exceedingly difficult.

But we have dwelt enough on the analyses of the APS Report on lasers and particle beams. More detail on the shortcomings of these analyses is contained in the accompanying LA-UR document, for those who may be interested.

Countermeasures. We would like to turn now to the Study's analysis of the ways in which a Soviet offensive strike planner might attempt to defeat our defenses by various ingenious strategems. This is the famous "countermeasures" question.

Perhaps the most important countermeasures are the ones directed against U.S. space-based defenses which attack the Soviet ICBMs from orbits over the USSR, while these missiles are in their boost phase and before they have deployed any of their warheads and decoys.

Among these boost-phase countermeasures, the most effective, from the attacker's point-of-view, is usually considered to be the fast-burn booster. The APS Report emphasizes this strongly, e.g., in its interim conclusion on p. 38.

Why is the fast-burn booster taken to be potentially so important to the Soviet offense and so deadly to U.S. defense plans? The basic reason is that the fast-burn booster is a hypothetical, specially designed ICBM that burns its fuel very rapidly and boosts its payload to full speed in about 60-100 seconds, in contrast to as much as five minutes required to reach full-speed for most existing Soviet and American ICBMs. Our boost-phase defenses depend to a considerable extent on tracking the Soviet ICBM by the heat radiation of its rocket exhaust; when this disappears, the tracking job becomes significantly more challenging.

A second advantage which the fast-burn booster confers on the Soviet attack planner derives from the fact that it burns out in the relatively dense air of the lower atmosphere. This is commonly regarded as affording complete protection to the Soviet ICBM from some of our most promising defensive weapons, which cannot penetrate to low altitudes. (The neutral particle beam, for instance, cannot get below about 70 miles above sea level.) As a result, according to the APS Report (on p. 38), the neutral particle beam is useless for boost-phase defensive operations, as is the x-ray laser (which the Report states—erroneously—cannot penetrate below 50 miles altitude).

But there is a fundamental error in the Study's reasoning about fast-burn boosters. This error involves the missile's warhead-carrying bus. After the booster burns out and falls away from the bus, the bus then proceeds to deploy its load of warheads. But the bus of a fast-burn booster cannot deploy its warheads immediately; it must wait until it has coasted up to an altitude of at least 90 miles.

If the bus doesn't wait to start to deploy warheads until it's at least 90 miles high, a terrible thing happens from the viewpoint of the attacker: namely, the residual atmosphere holds back the relatively lightweight decoys more than it does the heavier warheads, and enables the watching defense to discriminate trivially the real warheads from the decoys. We do not even have to go to the trouble of trying to discriminate the warheads from the decoys later in their attack trajectories—and doing this is one of the great challenges in the midcourse portion of strategic defense—because the Soviets have done the discrimination for us, by MIRVing their warheads too early in their attack.

Thus, the neutral particle and x-ray laser beams can both get down to 70 miles or less, but the ICBM bus has to rise to at least 90 miles to begin to release its warheads. This basic and unavoidable consideration opens up a window of opportunity—between no more than 70 miles and no less than 90 miles altitude—in which our defenses can attack the bus while it still has all of its warheads on-board and thus is just as valuable a target for the defense as is the booster itself.

How long is this window of opportunity unavoidably open? It takes the bus about 12 seconds to get from 70 to 90 miles altitude. This isn't very long, but it is enough for the neutral particle beam, and easily adequate for the x-ray laser beam. Even a very weak, brief pulse of atomic particles from the neutral particle beam, lasting only a few thousandths of a second, may be sufficient to introduce lethal glitches into the computers which navigate the bus and command its functions. An x-ray laser beam, lasting only billionths of a second, may smash the bus into tiny fragments and vapor—and its companion beams, simultaneously emitted from the same generator, may so smash all such buses, over an entire continental area.

All this also means that, no matter how quickly the booster may burn out, the chemical, excimer and free-electron lasers—all of whose beams may propagate all the way down to ground level—will have 100-150 seconds in which to engage the booster or (equivalently) its fully-loaded bus. This window is open very wide indeed.

Incidentally, the Soviets will encounter another unavoidable problem if they attempt to deploy their warheads too deeply in the atmosphere, over and above losing the effectiveness of their decoys. The drag of the residual atmosphere on the massive warheads, while relatively much less than that on the decoys, will still retard their motion, so that they will land at different points in the U.S. than those intended by the strike planner; in short, they will miss their targets. Moreover, the highly variable density of the upper atmosphere precludes the Soviets' advance prediction-and-correction for such drag effects, and later correction induces defense-exploitable sensitivities.

A degraded targeting accuracy of Soviet warheads would be one of the best presents which the USSR could give to the national security of America in the relatively near-term, because it would severely reduce the first-strike effectiveness of the present Soviet ICBM force against U.S. military sites. If the accuracy of the SS-18 warheads were degraded by even a few hundred yards—about that which premature MIRVing would entail—it would be a far less formidable first-strike weapon. That is a loss which the Soviets—having spent hundreds of billions of dollars on creating their present arsenal of highly accurate, high-yield warheads in the first place—would certainly be determined to avoid.

The interesting aspect of all these rather esoteric considerations in the present context is that *the telling objection to the anti-defense utility of the fast-burn booster—the fact that the Soviets cannot deploy warheads below 90 miles altitude—is contained in the APS Report itself.* It is displayed in a graphical figure on p. 50, on which a label ("assumed sensor resolution") declares explicitly that deployment of Soviet warheads and decoys below an altitude of 90 miles—150 kilometers—engenders a difference between the speed of the warhead and the speed of a decoy that is readily measurable by the defense with existing velocity-sensing technology.

It is therefore very difficult to believe that the author of the pertinent sections of the Executive Summary of the Report—or the interim conclusions on p. 38—which dismiss the efficacy of both neutral particle beams and x-ray lasers in boost-phase defensive operations could have understood the basic thrust of Figure 2.9 on the Report's p. 50. It is even more remarkable that none of the other Study Group members—or the senior reviewers designated by the APS Council—noticed this rather ruinous contradiction in the Report's reasoning and conclusions.

Another suggested Soviet countermeasure is the spinning of their ICBMs, which would act to distribute the energy of a U.S. defensive laser beam over a larger area of the missile skin, and thus diminish its lethal effect. This suggestion is discussed in the Report with all seriousness under the heading "Booster Rotation" (and can also be found in the "technical" discussions of missile defense distributed by the Union of Concerned Scientists). Spinning boosters as an offensive countermeasure is the kind of suggestion which a bright physics undergraduate might come up with, but even a minute of thought by an individual who knows the basics of missile design reveals that this suggestion has very little merit.

The basic reason is that the defensive laser systems are being designed to melt or blast a hole through the skin of a Soviet ICBM in less than a second. Therefore, the ICBM must rotate quite rapidly—at least once per second—to spread the laser energy around its circumference. This spinning would exert substantial centrifugal force on the walls of this tankage, which would have to be strengthened, at the cost of added weight and thus reduced payload. The result would be a major redesign of all Soviet ICBMs at very great expense, for a modest penalty imposed on the defense: a 2-3-fold increase in required laser system brightness.

No one with even a minimal understanding of missile engineering would suggest—as the APS Study Group does—that a spin rate of one revolution/second could be imparted to the Soviet ICBMs by "retrofit," i.e., by tinkering with them after they have already been built and slipped into their silos. Many additional, independent reasons behind this conclusion are discussed in the accompanying LA-UR document, e.g., on p. 34.

Finally, the APS Report took a look at the much-discussed possibility that the Soviets might plaster a coat of protective material over the surfaces of their ICBMs to shield them from the heating effect of continuous laser beam attack. The idea is that the energy of the laser beam would evaporate only the protective material, leaving the skin of the missile intact beneath. (Such shielding would be of essentially no utility against attack with x-ray laser beams, excimer laser beams or neutral particle beams, but it's a perennial favorite in SDI public debate anyway.)

The fundamental problem with this countermeasure is that the added weight of the shielding has to be compensated by a decrease in the weight of the payload; otherwise, the rocket will not be able to lift off the ground, or throw its payload over the required intercontinental distances. In other words, because of the weight of the shielding, the missile cannot throw as many warheads. The key question is, How many warheads must the Soviets off-load? Of the 10 warheads presently sitting on top of SS-18s, for example, how many must be discarded by the Soviets to compensate for the weight of an effective anti-laser coating?

The APS Report gives a detailed calculation of this problem, which produces an answer to this question. However, the answer is wrong. The reason is that, while the calculation is completely sound, the numbers which it assumes for its starting point are wrong. In particular, they underestimated the weight of the shielding which goes on the missile's second stage and on its bus by about a factor of four.

(The APS Report explicitly assumed that the amount of shielding on each stage of the SS-18 would be proportional to the *mass* of that stage. Actually, though, since the shielding is plastered over the ICBM's *surface,* the mass of shielding on each stage is proportional to the *surface area* of that stage. This simple conceptual error led the APS Study Group to underestimate severely the required mass of shielding on the upper stage and on the bus. The calculation is done correctly and in detail in the accompanying LA-UR document, on pp. 28-33.)

Because of this error in calculating the amount of shielding on the upper stages, the APS Report substantially underestimated the number of warheads that would have to be thrown overboard by the Soviets, to compensate for shielding their SS-18s against our first-generation defensive lasers systems.

For example, if the Soviets put six metric tons of anti-laser shielding on an SS-18—which would represent about a half-inch of shielding over the entire skin of the missile—the APS Report states that the SS-18 could still carry five warheads out of its nominal complement of 10 warheads. That doesn't sound like too heavy a penalty for the Soviets to pay to ensure the survival of the most effective of their present first-strike weapons. The correct answer, however, is that they would have to take off a total payload mass equal to that of *all* of the 10 warheads. Even if they off-loaded a corresponding amount of fuel from the bus, they would still have to unload between 5 and 10 warheads. If they included a prudent complement of penetration aids—decoys, chaff, etc.—in the bus, along with the gear to deploy it, the remaining number of warheads would be 1 or 2, a reduction of three- to five-fold from the estimates of the APS Study.

In other words, a fearsome Soviet weapons system presently capable of throwing as many as 3000 one-megaton-scale warheads with very high accuracy at America—a potent first-strike capability—would be reduced to something far less—qualitatively less—threatening by a rational Soviet response to the mere *existence* of an American strategic defensive capability based on any of several types of in-space laser systems. Any attrition of the attack by the *operation* of the defensive system would be an additional benefit.

Simply bringing a credible strategic defensive system into existence would thus be a manifestly effective way of sweeping SS-18s close to obsolescence.

Conclusions. The APS press release, announcing this Study Group Report on Directed Energy Weapons, states that the members of the Study Group and of the Review Committee which monitored and appraised the Report on behalf of the APS Council comprised a wide range of talent and experience in many disciplines of physics and technology.

How can that undoubted range of experience and expertise be reconciled with the many fundamental errors in this Report, and with its many statements that directly conflict with the realities of military and space engineering? How can we explain these errors, these basic misconceptions of strategic defense architectures and these apparent sins of ignorance which always lead to conclusions that denigrate the effectiveness of a defense against Soviet ballistic missile attack and exaggerate the effectiveness of possible Soviet countermeasures against a defensive system? We have no ready answers to these questions.

We note, however, that when the many necessary technical corrections are made to the APS Report, there are no surprises left in it, no issues remaining that were not already known long since and taken into account by workers and program managers alike throughout the directed energy weapons community. Even the decade-long developmental time scales which the Report forecasts come as no surprise to the community.

We do have some methodological criticisms to offer, in the hopes that improvements can be made in future efforts of this kind and in the expectation that a better understanding will result, on the part of the Congress and the public, of the problems inherent in the APS effort.

First, the Study effort didn't invite pre-publication technical commentary on the results of its work from any of the major directed energy weapons programs which it reviewed, and particularly did not do so from SDIO's Directed Energy Office. (It was required to request classification review from SDIO/DEO, and did so; however, a technical review which it could have had concurrently was not requested.) It thereby failed to benefit from the type of feedback which the General Accounting Office routinely receives near the conclusions of the studies which it does for the Congress; it also failed to benefit its readership with the documented responses from the people and programs being reviewed which GAO study reports routinely include for its Congressional readership. The reasons for these failures are not at all clear, particularly when it is considered that normal reviewing practices automatically avoid them.

Second, the standard in the technical professional community is for *all* studies on *all* technical matters to be subjected to *peer review* prior to publication, with the peer review process refereed by a senior, impartial expert. In practice, the senior referee is the editor of a professional journal to whom a paper is submitted for publication, and the peer review is conducted by *at least* two *anonymous* experts in the field selected by the editor; at least one of these peers is typically chosen to be capable of *critically* reviewing the submitted work. The feature of anonymity is introduced to encourage utter candor in the review process to the maximum feasible extent. Only when the editor is satisfied that the author's peers have searchingly examined the submitted work—and that all required improvements have been made in it—is it accepted for publication.

Regrettably, the APS Council elected not to have the Study Group Report peer-reviewed. This was a serious mistake.

No physicist would read a physics journal in which papers were published simply if they were submitted with an endorsement by some senior physicist who might also be a friend of the author or supportive of the paper's conclusions. The unalterable standard in the physics community—and, indeed, in the entire technical community—is "If it isn't peer-reviewed, it's not worth reading." No physics journal stays in business very long once the community loses faith in the vigor—and honesty and competence—of its pre-publication peer review process.

Instead of following this procedure, the APS Council had the Report publicly "attested to" by six very senior and eminent physicists. As distinguished as these gentlemen are in physics, they are not expert in the technological fields under APS review: none of them have worked in these technology areas for at least the past quarter-century; indeed, none of them have *ever* worked on the military applications of directed energy *at all*. Such pertinent knowledge as they have is of the underlying basic physical principles, or derives from indirect sources, such as briefings. The SDI research program, however, is primarily—nearly exclusively, in resource terms—one of engineering and technology, not fundamental physics. The appropriateness of the APS senior review group process therefore is open to question.

Third, two of its six members of the APS's senior review group are on record as being broadly opposed to the SDI, and two others are known to us as having expressed deep reservations in private about the SDI. Having at least two-thirds of a jury pre-disposed to convict before the trial opens would challenge the abilities of even the best defense lawyer.

However, the APS's senior review group, like the Study Group itself, apparently didn't invite or entertain any technical criticisms or dissents regarding the Report. The defense lawyer's job is even tougher when he isn't allowed to present a defense.

Fourth, on April 24, the APS Council, upon being presented with the Study Group's Report and the supporting testimonial from its senior review group, issued a formal statement condemning *all possible prospects* for near-term deployment of strategic defenses. *This condemnation was remarkable for its being based on no technical evidence presented to the Council,* for it was explicitly acknowledged that directed energy weaponry—the subject of the only technical report concerning the SDI known to Council members—is not being considered for any major role in the architectures being evaluated for near-term strategic defenses.

That the APS Council was willing to enter the ongoing policy debate on the near-term aspects of strategic defense *on the basis of no technical studies or reviews* done by it or under its auspices—especially after it had commissioned a study on some of the long-term technical aspects of strategic defense, namely directed energy weaponry—necessarily raises questions as to its objectivity on this entire issue, including its chartering, appointment and supervision of the Directed Energy Weapons Study Group and the Study's senior review group.

Now the Council is not empowered to act for the entire Society in basic policy matters; policy stances can be taken by the Society only upon vote of the full membership. Also, the Society is precluded by its charter and by its tax-exempt status from entering public policy debates or attempting to influence the legislative process. The APS Council may well have contravened these limits of the Society's charter and of its status with the IRS in the action which it took on April 24th.

We thank you very much for the opportunity to appear before you today, and to discuss these crucial matters with you.